ENGINEERING WORKS PRACTICE

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Modern Methods and Materials

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MODERN METHODS AND MATERIALS

ELECTRIC ARC WELDING

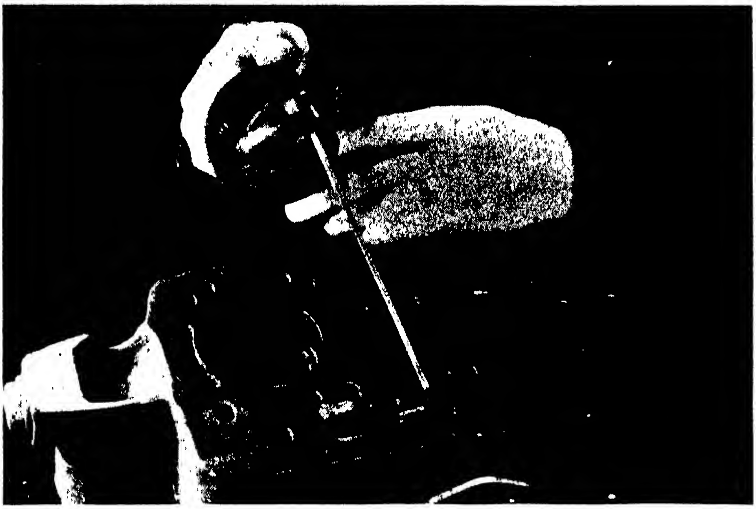


FIG. 1.—CRACK IN CYLINDER BLOCK ABOUT TO BE REPAIRED BY ARC WELDING

AN electric arc is simply a sustained spark between two terminals. In arc welding this is formed between the work being welded and an electrode held in the operator's hand and connected to the welding machine. The tremendous heat generated at the arc melts the work at the point of welding and also melts the end of the electrode. Additional metal is thus deposited into the weld joint from the electrode.

METALLIC ARC WELDING

Metallic arc welding can be divided broadly under two headings, namely, welding with a direct-current arc, and welding with an alternating-current arc.

Equipment for D.C. Welding

The equipment required for this type of welding is a D.C. welding generator which may be electrically driven from A.C. supply mains, or driven from a petrol engine mounted on the same baseplate. The generator must be specially designed

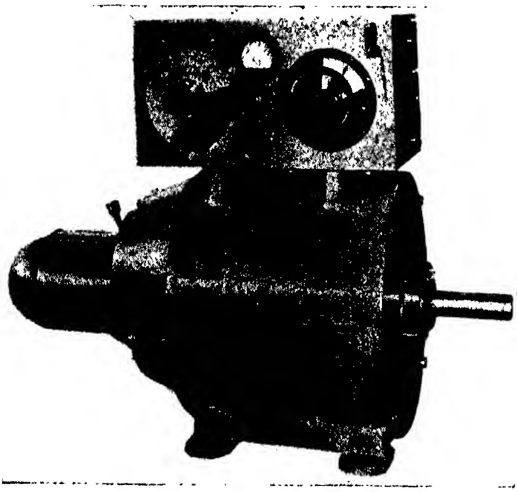


FIG. 2.—A D.C. WELDING GENERATOR AND CONTROL PANEL
(*Lincoln Electric Co., Ltd.*)

for welding purposes, so that it generates about 60 volts on open circuit, the voltage dropping to about 20 immediately the arc is struck.

Generators are made in various current ratings ranging from 100 amps. to 600 amps.

As a general rule, only one operator can work from each welding generator, as the voltage of the machine drops below the striking voltage as soon as one arc is in operation.

Fig. 4 shows, in a very simplified form, the general principle of the D.C. welding generator. It will be seen that the work is connected to one terminal of the generator, whilst the welding electrode is connected through a variable resistance to the other terminal. For heavy work the resistance is cut out, whilst for light work, where comparatively small current is required, the maximum amount of resistance is brought into the circuit.

Method of Connecting up a D.C. Welding Set

There are several different makes of D.C. welding sets obtainable. Each of these sets has its own special point of design, but the notes below can be taken as a general guide as to the manner in which sets of this type should be connected up before welding is begun.

(1) Connect one end of the "earth" cable to negative terminal on dynamo and other end to the work to be welded or the bench.

(2) Connect end of "welding" cable fitted with an eye to positive terminal on machine, and make sure that connection to electrode holder at the other end is satisfactory and insulated properly. Hang the electrode holder on an insulated hook near work bench or lay on a piece of wood to prevent short circuit. (Both of the above cables should be of sufficient cross section to carry the welding current, i.e. on a standard plant giving 200 amps. the cables should be 19/0·064 and efficiently insulated.)

(3) If a shunt-field regulator is fixed near the generator, see that one insulated wire connects one terminal to the shunt-field terminal on the generator

and the other terminal on the regulator is connected to main negative terminal.

If a portable regulator is employed near the work, connect one terminal to the work (or negative cable) and the other to the small centre terminal on generator marked "Shunt Field."

Shunt-field Wiring

Shunt-field regulator wiring need only be of small cross section, i.e. 3/20 cable, as only very low currents are carried, but it should be very efficiently insulated.

Making the Connections

It is of extreme importance that all joints should be properly made, as a bad connection can produce a drop of several volts which would be sufficient to interfere materially with the correct working of the plant.

Alternating-current Welding Plant

Although many modern D.C. welding sets are driven by an alternating-current motor connected to A.C. supply, these do not come under the classifica-

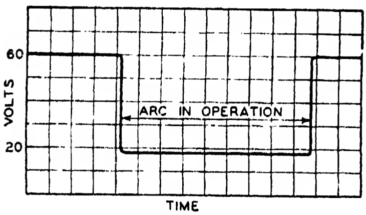


FIG. 3.—SHOWING HOW GENERATOR VOLTAGE DROPS DURING THE WELDING OPERATION

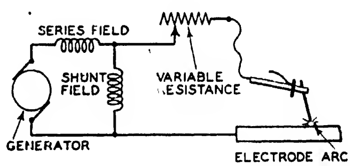


FIG. 4.—SIMPLE DIAGRAM OF D.C. WELDING CIRCUIT

tion of A.C. welding sets. This term refers to welding which uses an A.C. arc, the energy being supplied to each welding point from a welding transformer set.

The latter consists essentially of a suitable transformer to reduce the supply voltage to a sufficiently low value for welding purposes and a regulating device to control the output of the plant to the requirements of the work in hand.

Alternating-current welding plant is lower in first cost than a similar-capacity direct-current plant, is more economical to run, costs nothing for maintenance over exceptionally long periods, is practically silent in operation, and the arc is unaffected by magnetic "blow."

Types of Electrodes Required for Alternating Current

It has, however, certain limitations, and on some classes of work direct current is to be preferred or is even a necessity.

It is only with great difficulty that bare wire or lightly coated electrodes can be deposited with the standard type of A.C. plant, and with the majority of electrodes available for welding alloy or non-ferrous metals, direct current is to be preferred. On the other hand, most of the modern extruded or heavily fluxed electrodes will work equally well on A.C. as on D.C. for the welding of iron or steel.

Electrodes coated with fluxing materials of a highly refractory nature will need higher arc voltages than those of easily fusible materials, because of the greater amount of heat diverted to melt the coating, and for the same reason a

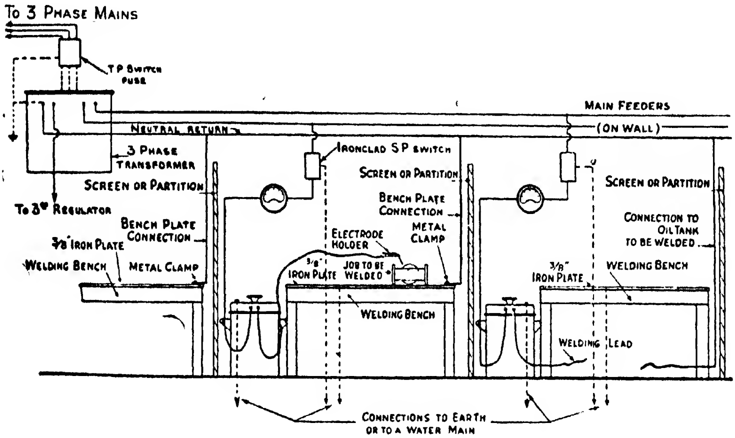


FIG. 5.—MULTIPLE-OPERATOR A.C. WELDING PLANT
Showing arrangement of welding bays, wiring, and earthing connections

higher open-circuit voltage will be necessary, as a prolonged period of retarded activity at each half-cycle would cause the arc to be completely extinguished.

Multiple-operator A.C. Welding Plant

As the transformer part of an A.C. welding equipment can be made up to any capacity, and can be designed so that the secondary voltage varies only within small limits over a wide load range, it is a simple matter to connect any number of reactance coils or regulators up to the capacity of the transformer to form a multiple operator unit (Fig. 5).

Notice that the top of each welding bench consists of a $\frac{3}{8}$-in. iron plate, so that work placed on the table automatically becomes connected to one side of the welding circuit. Each electrode holder is connected to a regulator, the return circuit from each passes through an ammeter and ironclad switch to the appropriate transformer terminal.

The Importance of Earthing

Reference to Fig. 5 will show that the welding bench and also the switch and regulator casings must all be connected to earth. Although the welder cannot be protected from the voltage between the electrode and earth, the above precautions ensure that the danger is limited to this one point, providing that all the rest of the circuit is well insulated, and any metal surfaces, such as meter cases, switchgear, and so on, are connected to earth.

A word should be said at this point in favour of yarn-wound electrodes, the covering of which is almost an insulator, against rods having a metalliferous paste covering, which are obviously more liable to give the welder a shock when inserting them into an electrode holder.

Those in charge of welding operations should consider it their duty to instruct learners fully in particular of any risks and to ensure that the cables and electrodes used are kept in good condition and that the welders are provided with gloves, which must be kept dry.

For working in the open, rubber boots are highly desirable, as these provide excellent protection from shock, and it is suggested that men should be encouraged to wear them particularly when site welding under damp conditions.

The danger of shock causing an accident in the case of ship work is very slight if the normal precautions are taken, and in cases where men are working on a wooden floor, it is reduced to a minimum. When the floor is earth or concrete, a small wooden board for welders to stand on could be used, particularly in cases where a man may be abnormally sensitive to electric shock.

Home Office Regulations

The attention of all concerned with electric welding is specially directed to the Home Office Memorandum on Electric Welding, which is obtainable from His Majesty's Stationery Office. The introduction to these regulations states that the process of electric arc welding by hand is being widely adopted in engineering works and repair shops in shipyards, and for constructional and repair work *in situ* on other premises. While the onus of providing for the working of the process in a safe manner rests with the occupier of the works, the workman is also responsible for using the safeguards provided in a proper manner.

Precautions required in respect of danger when electric arc welding is being undertaken are from:

(1) Electric shock.
(2) Radiations from the arc.
(3) The scattering of hot particles or globules of metal.
(4) Flying pieces of sharp slag when being chipped away after welding.

The Home Office authorities favour the use of direct current, as when direct current is used at the right pressure the danger of a serious electric shock is practically negligible. In view of this, adequate precautions against accidental electric shock have to be taken when using alternating current. A most important

precaution concerns the construction of the electrode holder. This should be provided with a handle of tough, non-ignitable, insulating material, so constructed that the welder cannot touch any live part with the hand with which he holds it.

Special risks mentioned in the memorandum include welding of stagings, boiler work, and rail welding.

An interesting section is devoted to protective glass, which should always conform to that specified by the British Standards Institution in their British Standards Specification No. 679—1947, "Protective Filters for Welding and Other Industrial Operations."

Electrodes

Metallic arc welding is essentially a method which uses the heat of the arc for the purpose of creating fusion, but it makes use of a filler rod as the electrode, and therefore does not require an auxiliary current carrier.

Electrodes for arc welding can be divided into the following three classes:

Bare Wire Rods

Bare electrodes of any ferrous metal hardly need description. Experience shows that there is very little difference in the composition of the electrode.

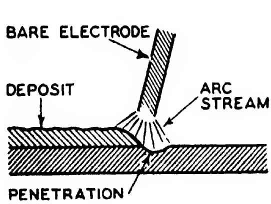


FIG. 6.—BARE ELECTRODE

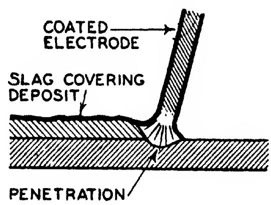


FIG. 7.—COATED ELECTRODE

Oxidation has a maximum effect both in respect of the iron and any constituent which is easily oxidised at high temperatures.

The arc voltage for welding with bare wire rods is lower than that usually required for dipped and coated electrodes, the voltage being about 20 volts. The current value varies from 150 amps. to 300 amps., according to the size of rod used.

Dipped or Light-coated Electrodes

Dipped or light-coated electrodes are dipped in some mixture which, on drying, leaves a thin skin of the solids in the mixture. This thin coating affords some protection against oxidation of the electrode surface, and may be of such composition as to provide some fluxing action, but a coating of this character is sufficient to provide the quantity of flux required for some types of work.

It is necessarily fragile and easily removed by handling, but such dipped

electrodes are an improvement on bare electrodes and give sufficiently good results for some jobs.

The medium-coated electrode, while coming within the classification of a light-coated electrode, is superior to it, and can be welded with A.C. The medium-coated electrode, however, does not compete with the heavy-coated type.

Heavy-coated Electrodes

Heavy-coated electrodes are covered with a material of substantial thickness and solidity, calculated to provide protection to the electrode.

Flux-covered electrodes have in general a spiral winding of asbestos yarn as the basis of the covering. Asbestos is a valuable flux in itself, as it fuses and combines with iron oxide into a compound silicate which, being very light and mobile, is easily removed after solidification, leaving a clean surface—an important advantage for work which requires more than one run of welding. Asbestos yarn also makes an excellent vehicle and support for the other constituents of the covering, and with a suitable binder makes a tough-surfaced sheath to the metal core. These electrodes, therefore, travel and handle without loss and damage.

Electrodes for mild-steel welding should always be specified in accordance with B.S.S. 639, Class A, B, C, or D, depending upon the mechanical properties required in the deposited weld metal. Electrodes are manufactured for welding: mild steel; high-tensile low-alloy steels; chrome-nickel "stainless steels"; chrome-molybdenum "aircraft" steels; high manganese steels; aluminium and most aluminium alloys; copper, bronze, and brass; nickel and cast iron.

Accessories

In addition to the different types of welding plant, the following accessories should form a part of every operator's equipment:

Electrode holder fitted with a length of flexible cable to connect plant.
Length of flexible cable for connecting the job to the plant.
Face screen or helmet, complete with coloured glasses.
Leather gauntlet gloves.
Apron for protection from possible burns.
Chipping hammer to remove slag from weld.
Wire brush for cleaning the weld after chipping.

Electrode Holders

An electrode holder is simply a clamping device for holding the electrode, and is provided with a handle for the operator's hand. The welding current is conveyed through the electrode holder to the electrode. The clamping device should be so designed as to hold the electrode securely in position, yet permit quick and easy change of electrodes, also providing good electrical contact. It should also be light in weight to permit ease of handling, yet sturdy enough to withstand rough usage.

Head Shields and Face Shields

To protect the operator's face and eyes from the direct rays of the arc, it is essential that a face shield or head shield be used. These shields are generally constructed of some kind of pressed-fibre insulating material, dead black in colour to reduce reflection. The shield should be light in weight, and designed to ensure the greatest possible comfort to the welder or user.

It is important that no screws or rivets *go right through* the insulating material from which the helmet is made, as otherwise there is risk of the operator receiving an unpleasant, if not dangerous, shock in the face should he accidentally touch such pieces of metal with his electrode holder.

Protective shields are provided with a glass window, the standard being 2 in. × 4⅛ in. The glass should be of such composition as to absorb the infra-red rays, the ultra-violet rays, and most visible rays emanating from the arc. In selecting welding lens, it is important to consider the manufacturer's reputation and his experience in the use of welding equipment as well as results of scientific tests of the lens. A welding lens, which is guaranteed to absorb 99·5 per cent. or more infra-red rays and 99·75 per cent. or more ultra-violet rays, is available. This lens has been reported as absorbing 100 per cent. of these rays by actual tests by the U.S. Bureau of Standards.

The welding lens in the head or face shield is protected from molten metal splatter and breakage by a chemically treated, clear, "non-splatter" glass covering the exposed side of the lens.

Special goggles are used by welders' helpers, foremen, supervisors, inspectors, and others working close to a welding arc to protect their eyes from occasional flashes. A popular goggle has adjustable elastic head-bands, and is light, cool, well ventilated, and comfortable. Clear cover glasses and greenish-tint lenses in various shades are available for this goggle.

Aprons

During the arc-welding process some sparks and globules of molten metal are thrown out from the arc. For protection from possible burns it is advisable that the operator wear a leather or protective apron. Some operators also wear spats or leggings and sleevelets of leather or other fire-resisting material. Some sort of protection should be provided for the operator's ankles and feet, inasmuch as a globule of molten metal can cause a small but painful burn to the foot before it can be extracted from the shoe. Turn the trousers down at the bottom so that molten metal will not fall in the turn-ups.

Gloves

A gauntlet type of glove, preferably of leather, is generally used by operators for protection of the hands from the arc rays, spatter of molten metal, sparks, etc. Gloves also provide protection when handling the work.

Manipulating the Welding Electrode

When using electrodes with extruded coating, a gaseous shield is formed over the work at the point at which welding is taking place. This effect is shown

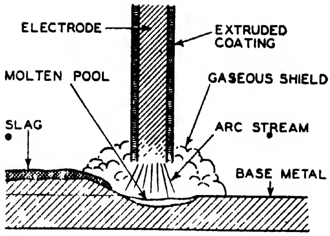


FIG. 8.—ILLUSTRATING THE ACTION OF A HEAVILY COATED ELECTRODE DURING THE WELDING OPERATION

Note the formation of a protective shield of vapour above the weld.

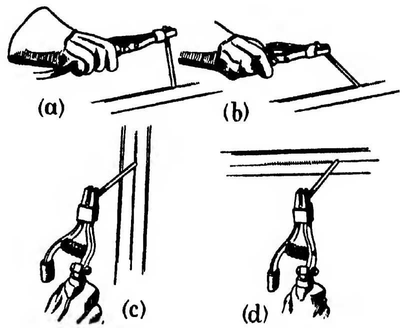


FIG. 9.—ILLUSTRATING THE CORRECT (*a*, *c*, AND *d*) AND INCORRECT METHODS (*b*) OF MANIPULATING THE WELDING ELECTRODE

diagrammatically in Fig. 8. In order to obtain the maximum advantage from this protective vapour, the electrode must be kept at the proper angle during welding. Thus the method of holding the electrode whilst the welding operation is in progress has an important influence upon the quality of the weld produced.

Fig. 9 (*a*) shows the correct angle between the electrode and the work for "downhand" welding.

Fig. 9 (*b*) shows the incorrect method, which will not yield satisfactory results.

Fig. 9 (*c*) shows the method of holding the electrode when welding a vertical seam, and Fig. 9 (*d*) shows the angle to be used in overhead welding.

Arc Welding Procedure

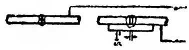
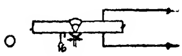
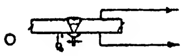
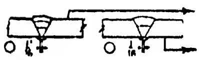
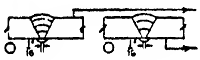
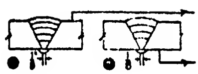
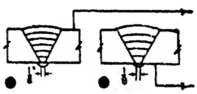
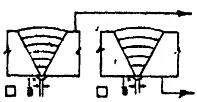
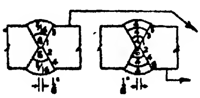
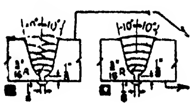
There are three important points to be observed in all arc welding. The first point is to decide whether a particular joint is suitable for welding in a single run. With the smaller sizes of joints there is no difficulty in obtaining a strong and sound weld in one operation, but, as the size of the joint increases, it becomes necessary to make two, three, or more runs in order to obtain a weld having the required strength.

The second important factor influencing the quality of the work is the size of the electrode. Where several runs are necessary to complete the joint, a smaller size of electrode may be desirable, but this is not an invariable rule.

The third point is the selection of the proper value for the welding current. The tables shown on pages 10, 11, and 12, and which are based upon information supplied by Murex Welding Processes, Ltd., makers of the well-known "Fastex 5" welding electrodes, show the recommended technique to be followed in welding various types and sizes of butt joints and fillet joints respectively.

It will be noticed that in most cases alternative methods of working are

ARC-WELDING PROCEDURE FOR DOWNHAND WELDING BUTT WELDS

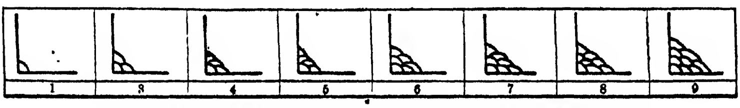
Plate Thickness In	*Edge Preparation 60° V Preparations unless shown otherwise*	*Number of Runs No.*	*Gauge of Electrode S.W.G.*	*Length of Weld per Electrode Gauge/In*	*Welding Current Amps.*
$\frac{1}{8}$		2	8	8/21	170
		1	8	8/14½	170
$\frac{3}{16}$		1 1	10 10	10/15 10/11	100 120
		1 1	10 8	10/15 8/16½	100 170
$\frac{1}{4}$		1 1	10 8	10/15 8/9	100 170
		1 1	10 6	10/15 6/12	100 210
$\frac{5}{16}$		1 2	10 8	10/12 8/12	100 170
		1 1	10 6	10/12 6/8	100 210
$\frac{3}{8}$		1 3	10 8	10/12 8/12	100 170
		1 2	10 6	10/12 6/12	100 210
$\frac{1}{2}$		3 2	8 8	8/12 8/7	150 170
		1 1 2	8 6 6	8/12 6/12 } 6/9 }	150 210
$\frac{5}{8}$		1 3 1 1	8 8 8 8	8/12 8/9 } 8/6 } 8/5 }	150 170
		1 1 1 1 1	8 6 6 6 6	8/12 6/12 } 6/10 } 6/6 } 6/5½ }	150 210
		1 1 1 1 2	8 6 6 6 6	8/12 6/12 } 6/10 } 6/9 } 6/6 }	150 210
		1 2 2	8 4 4	8/12 4/12 } 4/6 }	150 250
		2 2	6 $\frac{5}{16}$	6/16½ $\frac{5}{16}$/12	200 560
		1 1 2 2	4 6 4 4	4/16½ 6/16½ 4/12 4/9	340 240 340 340
		1 8	4 4	4/20 4/12	240 340
		1 5	4 $\frac{5}{16}$	4/20 $\frac{5}{16}$/12	240 560

The above data refer to welding with Murex "Fastex 5" electrodes.

Arc-welding Procedure for Horizontal-vertical Fillet Welds

Size of Fillet In.	*Throat Thickness In.*	*Number of Runs No.*	*Gauge of Electrode S.W.G.*	*Length of Weld per Electrode Gauge/in.*	*Welding Current Amps.*
$\frac{1}{8}$	0·088	1	10	10/15	120
		1	8	8/23	170
$\frac{3}{16}$	0·133	1	10	10/11	120
		1	8	8/13	150
$\frac{1}{4}$	0·176	1	8	8/10	170
		1	6	6/12	225
		1	4	4/14	290
$\frac{5}{16}$	0·221	3	10	10/9	120
		1 1 1	8 8 8	8/18 8/17 8/12	165
		1	6	6/8½	220
		1	4	4/11	300
$\frac{3}{8}$	0·265	3	8	8/12	170
		3	6	6/16	200
$\frac{1}{2}$	0·354	6	8	8/16	170
		4	6	6/14	230
		3	4	4/18	300
$\frac{5}{8}$	0·441	8	8	8/11	170
		6	6	6/12	210
		5	4	4/13	250
$\frac{3}{4}$	0·530	9	6	6/12	210
		7	4	4/13	250

Key to Welding Procedure for Number of Runs

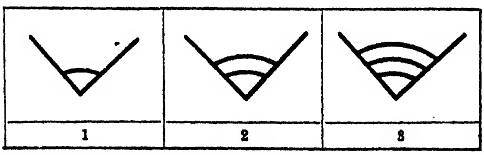


The above data refer to welding with Murex "Fastex 5" electrodes.

Arc-welding Procedure for Tilted Fillet Welds

Size of Fillet In.	*Throat Thickness In.*	*Number of Runs No.*	*Gauge of Electrode S.W.G.*	*Length of Weld per Electrode Gauge/in.*	*Welding Current Amps.*
1/8	0·088	1	10	10/16½	120
		1	8	8/26½	170
3/16	0·133	1	10	10/8	120
		1	8	8/10	170
		1	6	6/22	210
1/4	0·176	1	10	10/12	120
		1	10	10/6	120
		2	8	8/12	170
		1	6	6/12	210
		1	4	4/18	250
5/16	0 221	2	10	10/12	120
		1	10	10/6	120
		2	8	8/12	170
		1	8	8/22	170
		2	6	6/12	210
		1	4	4/13	250
3/8	0·265	1	10	10/12	120
		2	10	10/6	120
		1	8	8/12	170
		1	8	8/6	170
		1	6	6/12	210
		1	6	6/9	210
		1	4	4/8	250
1/2	0 354	1	8	8/12	170
		2	8	8/6	170
		3	6	6/12	210
		1	6	6/19	210
		2	4	4/12	250
		1	4	4/25	250
5/8	0·441	1	8	8/9	170
		3	8	8/6	170
		1	6	6/9	210
		2	6	6/6	210
		2	4	4/12	250
		1	4	4/8	250
3/4	0 530	1	8	8/12	170
		3	8	8/6	170
		1	8	8/4	170
		1	6	6/9	210
		3	6	6/6	210
		1	4	4/9	250
		2	4	4/6	250

Key to Welding Procedure for Number of Runs



The above data refer to welding with Murex "Fastex 5" electrodes.

given and, where a smaller size of electrode is necessary for the first run, this has been indicated.

To take an actual example, referring to the table on page 10, a $\frac{5}{16}$-in. butt weld may be completed either in three runs, using a No. 10 electrode for the first run and No. 8 for each of the remaining two runs, or this joint may be completed in two runs, using a No. 10 electrode for the first run and a No. 6 electrode for the second run; the correct welding current in each case will also be seen in the table.

Types of Joints

There are five general types of joints, namely: butt joints, T-joints, lap joints, edge joints, and corner joints.

Butt joints may be open or closed. In the open butt joint there is space between the adjacent edges; in the closed butt joint the adjacent edges are in contact with each other. In both open and closed butt joints the adjacent edges may be square or bevelled. When only one of the adjacent edges is bevelled from one side, the joint is known as a single-bevel butt joint. When both sides of only one edge of a joint are bevelled, the joint is called a double-bevel butt joint. Joints with both adjacent edges bevelled are known as V butt joints. When bevelled from one side only they are known as single-V butt joints (Fig. 10 (*a*)), and when bevelled from both sides are known as double-V butt joints (Fig. 10 (*b*)). Bevelled and V butt joints may be open or closed.

When the adjacent edges of a butt joint are cut from either one or both sides so as to enclose a U or two Us, they are known as a single-U butt joint (Fig. 10 (*c*)) or a double-U butt joint (Fig. 10 (*d*)) respectively. U butt joints may be open or closed.

In *T-joints* the vertical member may or may not be bevelled from one or both surfaces. When the vertical member is in contact with the horizontal member, it is known as a closed T-joint, and when there is space between the vertical and horizontal members, the joint is known as an open T-joint. When the vertical member is not bevelled, a square T-joint is formed. This type of T-joint requires a fillet weld. However, when the vertical members are bevelled either from one or both surfaces, they are known as single-bevel (Fig. 10 (*h*)) or double-bevel (Fig. 10 (*j*)) T-joints respectively.

Lap joints are formed when the surfaces of two parallel plates are in contact with each other and the edges of the two plates adjacent to the point of contact are not in line. The plain lap joint which requires a fillet weld, but which is more commonly known as a lap weld in this particular type of application, is illustrated in Fig. 10 (*g*). A type of joggled lap joint which requires a butt weld is shown in Fig. 10 (*f*).

A *corner joint* is similar to a T-joint, except that one member does not extend beyond the other member.

Edge joints are formed when the edges of the contacting plates are in the same plane, the contacting plates being on the same side of the plane.

Selection of Type of Joint

The selection of the type of joint to use in a particular application is governed by three factors:

(1) The load and its characteristics, that is, whether the load is in tension or compression, and whether bending, fatigue, or impact stresses in any combination are present.

(2) The manner in which the load is applied, that is, whether load application is steady, variable, or sudden.

(3) The cost of the joint preparation and welding.

Obviously, the joint to select is the one which meets the load requirements and costs the least.

Aid in selecting the best joint for given service conditions and cost is provided in the following detailed discussion of the principal types of joints.

Butt Joints

Butt joints are of several types, each having a number of variations. However, the general classification lists butt joints as plain, single-V, double-V, single-U, and double-U.

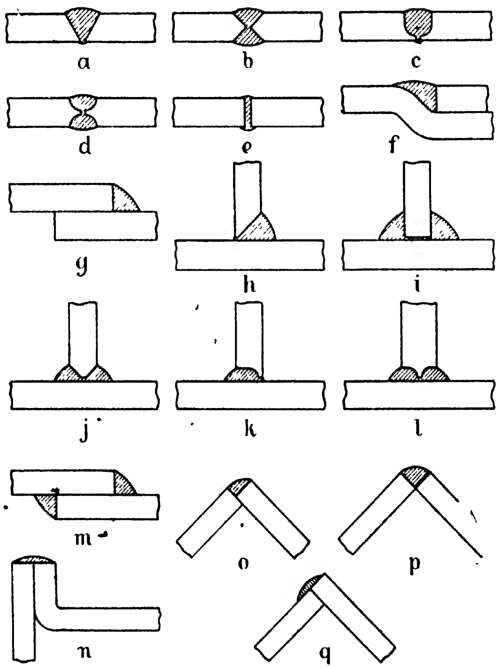


FIG. 10.—TYPES OF ARC-WELDED JOINTS

a—Single-V butt joint.
b—Double-V butt joint.
c—Single-U butt joint.
d—Double-U butt joint.
e—Plain butt joint.
f—Joggled lap joint.
g—Plain lap joint.
h—Single-bevel T-joint.
i—Plain T-joint.
j—Double-bevel T-joint.
k—Single-U T-joint.
l—Double-U T-joint.
m—Double-bead lap joint.
n—Edge joint.
o—Half-open corner joint.
p—Full-open corner joint.
q—Flush corner joint.

The plain butt joint (Fig. 10 (*e*)) is suitable for all usual loads, and requires full and complete fusion, particularly when load is of fatigue or intermittent nature. The base metal for this type of joint must be good weldable steel, since a large portion of the base metal is melted during welding. The thickness of plate on which the plain butt joint is used is generally $\frac{3}{8}$ in. or lighter when welded with metal electrode, and $\frac{3}{4}$ in. or lighter with carbon electrode, although this type of joint has been used on other plate sizes. Preparation for welding this joint is simple, requiring only a matching of the edges of the plate, separated by a distance dependent upon the plate thickness. Because of the simple preparation, the plain butt joint is low in cost.

The single-V butt joint (Fig. 10 (*a*)) is suitable for all usual load conditions. It is generally used with plate thickness considerably greater than the plain butt joint—$\frac{3}{8}$ in. or heavier—although its use on thinner plate is not unusual. Preparation is more costly then the plain butt joint and more electrode is used in welding.

The double-V butt joint (Fig. 10 (*b*)) is suitable for all usual load conditions. It is used for plates of greater thickness than the single V, and for work which can be welded from both sides. Cost of preparation for welding is higher than for the single-V butt joint, but double V requires approximately half as much electrode. Cost of machining should be weighed against the cost of welding, and the joint selection made accordingly.

The single-U butt joint (Fig. 10 (*c*)) is suitable for all usual load conditions, and is used for work of the highest quality. It replaces single- or double-V joints for joining plates $\frac{1}{2}$–$\frac{3}{4}$ in. thick, although it is also used on heavier plate. For plates of this thickness, single- or double-V joints would require a considerable amount of weld metal. Machining the plates to a single U reduces amount of weld metal needed, but increases machining costs. The joint is welded from one side except for a single bead, which is put in last on the opposite side from the U.

The double-U butt joint (Fig. 10 (*d*)) is suitable for all load conditions, and is used for welding heavy plates, $\frac{3}{4}$ in. and thicker—where the welding can be done from both sides. This joint requires less weld metal than the single U, but costs more to machine. Choice between double U and double V should be made by comparing the machining and electrode costs of the two, then selecting the joint which costs less.

T-joints

The plain T-joint (Fig. 10 (*i*)) corresponds to the plain butt joint, in that no machining of plates is required. The plain T is used for all ordinary plate thicknesses, principally for loads which place the welds in longitudinal shear. For severe impact or heavy transverse loads, the non-uniform stress distribution of the joint should be kept in mind and the stress intensity of the application duly considered. The plain T requires more weld metal, and therefore has higher electrode cost than other types of T-joints.

The single-bevel T-joint (Fig. 10 (*h*)) is suitable for much more severe loads

than the plain T, due to its better distribution of stress. It is employed, in most instances, for welding plates ½ in. or thinner in work which can be welded from one side only. While more costly to machine than the plain T, the single-bevel T-joint is lower in electrode costs.

The double-bevel T-joint (Fig. 10 (*j*)) is suitable for heavy loads in longitudinal or transverse shear in joining heavy plate where welding can be done from both sides. Double-bevel is somewhat higher than single-bevel T-joint in machining cost, but has lower electrode cost than some other types, such as plain T.

The single-U T-joint (Fig. 10 (*k*)) is suitable for severe loads, and while it may be used for usual size plates, it is generally applied to plates 1 in. and heavier. The welding is done from one side only. However, it is advisable to put in a final finish bead on the side opposite the U. Although somewhat more costly to machine than the single-bevel T-joint, the single-U T-joint is lower in electrode cost.

The double-U T-joint (Fig. 10 (*l*)) is suitable for exceedingly severe loads of all types in heavy plate—1½ in. and heavier—where welding can be done from both sides. Although the machining costs for the double-U T-joints are higher *than for other types of T-joints, less electrode is required; consequently, the cost per joint is reduced.*

Lap Joints

The single-bead lap joint (Fig. 10 (*g*)) is frequently used, and has the advantage of requiring practically no machining to fit the edges of the plate. When fatigue or impact loads are encountered, stress distribution should be carefully studied. Where loading is not too severe, the single-bead lap joint is suitable for welding plate of all thicknesses.

The double-bead lap joint (Fig. 10 (*m*)) is suitable for load conditions much more severe than can be met by the single-bead lap joint. In general, the two beads should be full size, although one bead may be smaller than the other in some instances. Because of its lower cost the double-bead lap joint is widely used.

Corner Joints

The flush corner joint (Fig. 10 (*q*)) is suitable where loads are not severe, or in welding plate 12 gauge and lighter. Although permissible for use on heavier plates, care should be taken that loading is not excessive.

The half-open corner joint (Fig. 10 (*o*)) is suitable for loads where fatigue or impact is not severe. This joint is generally used on plates heavier than 12 gauge, where the welding can be done from one side only. The "shouldering" effect of this type of joint aids welding by reducing the tendency to burn through the plates at the corner.

The full-open corner joint (Fig. 10 (*p*)) is suitable for severe loads in welding plate of all thicknesses, where the welding can be done from both sides. When

properly made, this joint is of such shape as to provide good stress distribution, thus permitting its application to fatigue or impact loads of all types.

Edge Joint

The edge joint (Fig. 10 (*n*)) is used in joining plates ¼ in. or thinner for light loads. Careful consideration must be given to the load conditions, especially impact and fatigue, as this type of joint is not suitable for severe loads.

DEFECTS TO BE AVOIDED

Some of the defects which may be encountered in the early stages of acquiring the proper technique of electric arc welding are shown in Figs. 11 and 12.

The causes of these defects are:

Butt Welds

Porosity and Slag Inclusions (Fig. 11 (*a*)).—Porosity is caused by the use of a light-coated or bare electrode.

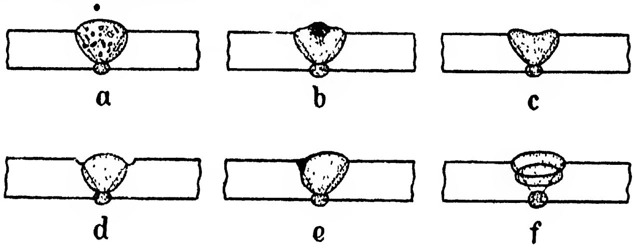


FIG. 11.—POSSIBLE DEFECTS IN BUTT WELDS

Slag inclusions are due to insufficient cleaning of the surface of the individual layers of weld metal before succeeding layers are deposited.

Overheating (Fig. 11 (*b*)).—Overheating of the weld may arise from using too high a current for the particular size of electrode, or, again, too slow a travel speed for the current used.

Hollow Surface (Fig. 11 (*c*)).—This defect is caused by attempting to fill up the V-joint of a butt weld by depositing a smaller number of runs than normal. Also, the same effect is produced by using an electrode and current too great for the particular job in question.

Undercutting (Fig. 11 (*d*)).—Undercutting may be caused by using too high a welding current, or too slow a rate of travel. Again, some electrodes are much more prone to undercutting than others, so discrimination should be shown in the choice of electrodes which are as free from this failing as possible. Undercutting can also be caused by the surface of the plates being dirty or badly scaled.

Weld Deflected to One Side (Fig. 11 (*e*)).—Generally caused by "Arc Blow." If the arc is powerfully deflected to one side of the seam by magnetic influences,

the weld metal will pile up on that side and slag will become trapped in between the weld and the plate on the opposite side. The earth connection should be examined to see that there is good electrical contact, and if this is not the cause of the trouble, the earth lead should be moved about in different positions until one is found which reduces the blowing effect to a minimum. Further causes of this defect are (1) insufficient "weaving" motion of the electrode, and (2) the electrode held at an incorrect slope, thus causing a bead of weld metal to be laid down that is too narrow to fill up the V.

Imperfect Root Penetration (Fig. 11 (*f*)).—Caused by using too large an electrode for the first run, thus preventing the weld metal from penetrating to the bottom of the V. Alternatively, this failing can be produced by drawing too long an arc or operating with too low a welding current.

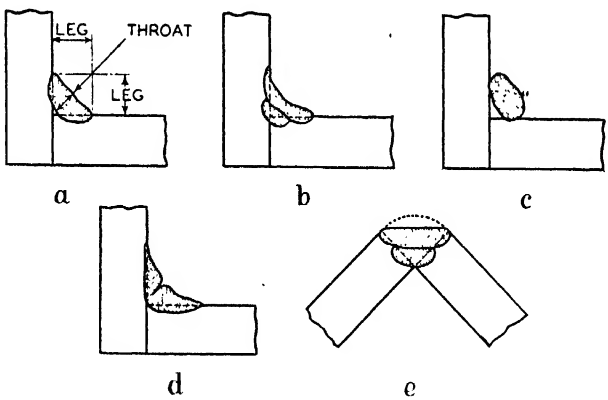


FIG. 12.—POSSIBLE DEFECTS IN FILLET WELDS

Fillet Welds

Defects which may be encountered in fillet welds are shown in Fig. 12.

Insufficient Root Penetration (Fig. 12 (*a*)).—This is due to attempting to deposit a large-size fillet weld in one run with a large electrode. Wherever possible, a No. 10 S.W.G. electrode should be used for the first run so as to secure full penetration into the root of the joint.

Undercutting (Fig. 12 (*b*)).—This is caused by using too fluid an electrode for the second run and attempting to weld without tilting the work. The electrode has had to be inclined to an almost horizontal position in order to cause the weld metal to be deposited on the vertical side. For welds of this kind which cannot be tilted an electrode having quick freezing properties is to be preferred.

Insufficient Penetration (Fig. 12 (*c*)).—This is due to using too low a welding current. The weld metal, besides failing to penetrate the root of the joint,

suffers from incomplete side-wall fusion, and, in addition, has a rounded surface.

Concave Welds (Fig. 12 (*d*)).—This defect is caused by using a fairly large-diameter electrode and too fast a travel speed, and particularly so if the electrode has a high degree of fluidity. The throat depth is much reduced because of the concave surface of the weld, and hence the weld itself is inherently weak along its centre plane.

Flat Surface Welds (Fig. 12 (*e*)).—This defect is due to absence of radius on the upper portion. The contour of the weld should have a radius approximately equal to the thickness of the plate, so that the thickness of the deposit is the same over the whole section.

DEEP-PENETRATION WELDING OF MILD STEEL

During recent years a further advance in the arc welding of mild steel has been the development of deep-penetration welding. Deep-penetration welding of mild steel makes joints by fusing together a considerable amount of base metal with the addition of a comparatively small quantity of filler metal. This is achieved by high heat input.

Heat in the arc is the product of arc voltage and welding current. The welding current is limited by the current-carrying capacity of the core wire of the electrode. Therefore the large amount of heat required for deep-penetration welding is obtained by increasing the arc voltage of the electrode, usually by the use of some cellulosic material in the covering.

Comparison of Costs

Deep-penetration welding, using deep-penetration electrodes, shows considerable savings in cost over normal welding with normal mild-steel electrodes. Savings are due to the fact that fewer electrodes are used per foot of weld, thus reducing both electrode consumption and welding time, with a corresponding reduction in overhead costs. There are further savings due to simplified plate preparation.

FIG. 13.—WELDING SPEED AND DEPTH OF PENETRATION

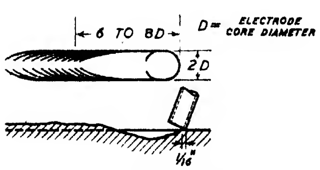


FIG. 14.—CRATER DIMENSIONS

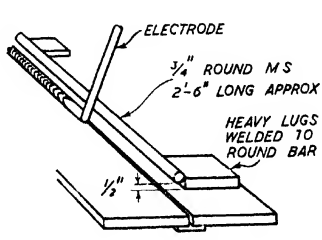


FIG. 15.—ELECTRODE GUIDE FOR DEEP PENETRATION WELDING

(*British Welding Research Association*)

DEEP-PENETRATION WELDING

Type of Joint	*Welding Procedure, Size of Plate, No. of Runs, Gauge of Electrode/in. of run*	*Welding Current Amps.*	*Electrode Consumption and Fusion Time per Foot of Weld*	
			Feet per Foot of Weld	*Fusion Time Minutes and Tenths*
Square Close Butt (one run each side of plate)	3/16-in. plate 2 runs 8/15	140	2·0	2·0
	1/4-in. and 5/16-in. plate 2 runs 8/15	140	2·4	2·4
	3/8-in. plate 2 runs 6/15	190	2·4	2·5
	1/2-in. plate 2 runs 1/4 in./15	*300*	*2·4*	*2·7*
	5/8-in. plate 2 runs 5/16 in./15	*450*	*2·4*	*2·7*
Square Gap 3/4-in. Butt (1/16-in. gap)	*2 runs 5/16 in./15*	*450*	*2·4*	*2·7*
Square Gap Butt with Backing Bar (Gap equal to one-half plate thickness)	3/16-in. plate 1 run 8/12	140	1·5	1·5
	1/4-in. plate 1 run 6/12	190	1·5	1·6
	5/16-in. plate 1 run 1/4 in./12	300	1·5	1·7
	3/8-in. plate 1 run 5/16 in./12	450	1·5	1·7
Prepared Butt with Backing Bar (Bevel plates 20° one side or 10° both sides. Gap 1/4-in. minimum)	Plate 7/16 in. and over 1st run 1/4 in./12	300	Larger electrodes may be used as width increases. For improved appearances medium penetrating electrodes may be used for final run.	
Tilted Fillet Welds (Electrode size preferably not more than one-half plate thickness)	3/16-in. fillet 1 run 8/12	120	1·5	1·6
	1/4-in. fillet 1 run 6/12	160	1·5	1·7
	5/16-in. fillet 1 run 1/4 in./12	240	1·5	2·0
	3/8-in. fillet 1 run 5/16 in./12	350	1·5	1·9
Standing Fillet Welds	3/16-in. fillet 1 run 8/12	110	1·5	1·7
	1/4-in. fillet 1 run 6/12	150	1·5	1·8

The above data refers to welding with "Weldeep" electrodes (BEAMA Code No. E125P). The electrode angle with line of joint is 40°. Deep-penetration fillets are 20 per cent. stronger than normal single-run fillets of the same nominal size due to greater root penetration.

(*The Quasi-Arc Co., Ltd.*)

Applications of Deep-penetration Welding

Deep-penetration welding can be applied to:

(1) Close square butt joints (one run each side) up to 3/8 in. thickness.

(2) Close square butt joints (one run one side) with detachable copper backing bar, up to 3/8 in.

(3) Square butts with welded backing bar up to 3/8-in. plate (one run).

(4) Narrow-angle V butts with backing bar, to any thickness.

(5) Root sealing runs without chipping on bevelled butts.

(6) Tilted fillets up to any size.

(7) Horizontal-vertical (standing) fillets.

(8) Edge welds and overlapping corner joints.

Operating Conditions

To ensure consistent results in deep-penetration welding, the following conditions must be maintained:

(1) Correct current (this varies with different types of electrodes).

(2) Correct angle of electrode to the work as recommended by electrode manufacturers. The electrode is moved along the seam without any weaving motion.

(3) Shortest possible length of arc. The coating at the tip of the electrode is maintained in contact with the unfused edge of the crater. The electrode position and crater dimensions corresponding to the correct welding speed for a close butt joint are shown in Figs. 13 and 14.

(4) The length of run per electrode (speed of travel) should be correct for the type of electrode employed. Lower speeds widen the weld surface and reduce penetration. If the speed of travel is too high, a deep undercut is left at the sides of the weld and the depth of penetration will be insufficient. In butt joints with a root opening, lower welding speeds may result in overheating or burning through the backing bar.

(5) The fit-up of the plate edges should be good throughout the length of the seam.

(6) All backing bars must be fitted and held in close contact with the plate, and be correctly centred under the joint. The backing bar must be thick enough to withstand overheating and burning through.

To assist in holding the electrode in the correct position at the centre of the joint in square butt seams, a guide as shown in Fig. 15 can be used.

Some deep penetrating electrodes can be used on both A.C. and D.C. The open-circuit voltage on A.C. may have to be as high as 100 volts. Owing to the higher arc voltage of some electrodes, the current available on any setting of the regulator may be less than the current obtained when using electrodes of lower arc voltage, and it may be necessary for the actual welding current to be checked with an ammeter.

CARBON ARC WELDING

Carbon arc welding was the original form of electric arc welding, and has much to recommend it in principle because it is a fusion by the electric arc of the original material, and so does not in general involve bevelling or scarfing of the joint to be welded or the addition of filler metal.

The molten metal with this process, as with bare-wire welding, is subjected to the contamination by the air resulting in brittle weld metal. Further, the arc, when used manually, has a tendency to wander. Consequently, its use was largely superseded by coated metallic electrodes. It has, however, more recently come into prominence again in the form of automatic welding equipment, whereby a magnetic field is superimposed on the arc to locate and concentrate it, and various means, such as gaseous shields and fluxes, are employed to eliminate the air and produce high-quality welds. Under these conditions it

CARBON ARC WELDING DATA

Metal Thickness S.W.G.	*Welding Voltage Volts*	*Welding Current Amps.*	*Carbon Size In.*	*Welding Speed Ft./hr.*
16	25	90–100	$\frac{3}{16}$	135
14	25	125–135	$\frac{1}{4}$	125
12	25	200–250	$\frac{1}{4}$–$\frac{5}{16}$	110
10	25	250–275	$\frac{1}{4}$–$\frac{5}{16}$	100

maintains its advantages of economy inasmuch as the parent metal is fused without the addition of electrode material.

Amongst skilled welders it is also used as a manual process for the repair of cast iron, using a high-silicon cast-iron filler rod, where the work can previously be preheated. It is also used for the welding of non-magnetic materials, as aluminium, copper, bronze, brass, "Everdur," and such metals. A filler rod of the same composition as the parent metal can be fed into the arc to provide additional weld metal.

Another application being used more and more is the welding of light-gauge mild steel by the carbon arc at low current values, employing a manual electrode holder providing in itself magnetic control. In this form it is also used in the welding of certain stainless steels. Carbon arc welding is a particularly economical method for welding "upturned edge joints" in sheet metal, since the parent metal is fused to form the weld, and no electrode metal has to be added.

Welding Procedure

Pointing of the Carbons.—The diameter of the point should be approximately half the diameter of the carbon used. The taper should be gradual back to the point where it is gripped in the holder.

Position of the Carbon in the Holder.—The carbon should be gripped as close to the arc as practical, as if a long length of carbon is exposed, the heating causes the carbon to vaporise and burn very rapidly, giving excessive wastage.

Polarity.—Electrode negative should be used in almost all cases.

Currents.—The proper current to be used depends upon the work to be done. The accompanying table will serve as a guide. The currents given are about the maximum which should ever be used. Smaller currents may be used, depending upon the weight or thickness of the base metal.

Because of its fundamental economy, the process as at present developed should be better known, and its application may be expected to extend.

NOTES ON TESTING

The welding operative can apply three practical tests to his specimen welds to make sure that he has acquired the proper technique. These three tests are illustrated in Figs. 16 (*a*), (*b*), and (*c*).

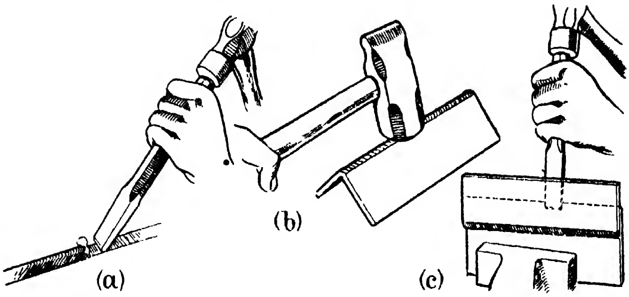


FIG. 16.—METHODS OF TESTING SPECIMEN WELDS

Test No. 1 (Fig. 16 (*a*))

Lay down a straight bead of weld metal, of even formation, from one full length of electrode, without breaking the arc. The plate should then be clamped in a vice, and with a hammer and chisel the bead of weld metal chipped away from the plate. If the weld is a good one, it will be united perfectly homogeneously with the parent metal, and every part of it will have to be cut with the chisel before it can be removed.

Test No. 2 (Fig. 16 (*b*))

Using $\frac{3}{16}$-in. or $\frac{1}{4}$-in. plates, tack them together edge to edge to form a right angle with the edges of the plates making an open 90° channel. A single-run weld is then laid down on the outside, with particular care being taken to see that full penetration is secured and that the weld is visible all along the inside. The surface of the weld should be well rounded and not flat, otherwise there will be a plane of weakness down the centre where the thickness of the deposited metal would be less than the plate thickness. To test the weld, the piece should be placed on an iron floor with the apex uppermost, and then flattened out with a sledge hammer. If the weld is sound and there is full penetration the whole length, the plates will not separate easily, but will bend before finally breaking.

Test No. 3 (Fig. 16 (*c*))

Two plates approximately the same size as those used for the other tests should be tack welded, one on top of the other, so that there is about 3 in. of overlap. A fillet weld is then laid down on one side so that the joint is completely filled. After the weld is completed the sample should be clamped in a vice and the two plates driven apart by means of a hammer and chisel. In this manner a fracture will take place roughly along the centre line of the weld and allow the deposit to be examined. If there has been any lack of side-wall fusion, this will be revealed by the weld coming away bodily from the plate in that particular place.

THE ARGONARC WELDING PROCESS

THE Argonarc process is the only known method of fusion welding aluminium and light alloys without necessitating the use of a flux.

Manual Argonarc welding is particularly suitable for the production of welded products in stainless steel, aluminium, and magnesium. The process is also suitable for the repair of broken and defective castings, extruded sections, and forgings.

In this process the heat source is obtained by striking an arc between the workpiece and a tungsten electrode; if it is necessary to use a filler rod, this is added separately in a manner similar to that used in normal gas welding. Throughout the welding operation the electrode, the arc, and the welding zone are shielded completely by an atmosphere of argon gas. Welding speeds are generally higher than those obtained with gas-fusion welding processes, and no after-weld treatment is necessary unless the finished surface of the job requires to be highly polished.

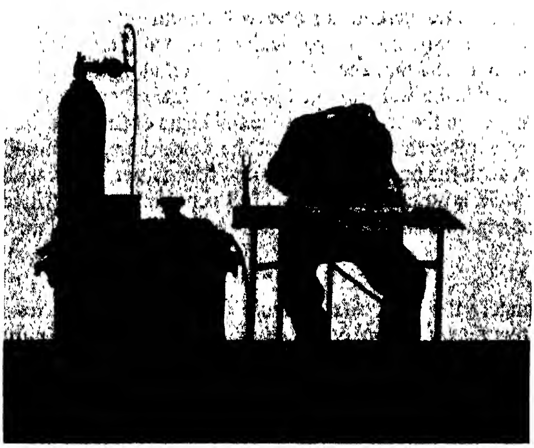


FIG. 1.—THE ARGONARC WELDING EQUIPMENT

Showing welding transformer and argon gas cylinder on left.
(*The British Oxygen Co., Ltd.*)

Welding Torch

Two types of welding torch have been developed for the Argonarc process: the Mark II torch, suitable for welding light sheet metals, and the Mark III, suitable for single-run welding of heavy gauge sheet and plate up to ¾ in. thick. Both of these torches are designed for manual welding only, but a torch for automatic machine welding, namely the Mark IV, suitable for all thicknesses of

metal, is in the course of development.

The argon gas is supplied to the torch from a cylinder, and passing through the body of the torch it emerges from a ceramic shield or hood giving an even flow of gas around the electrode which is fitted into the torch.

FIG. 2.—WELDING AN ALUMINIUM-ALLOY CASTING BY THE ARGONARC PROCESS

The welding transformer is a type specially developed for aluminium welding. (*The British Oxygen Co., Ltd.*)

Choice of A.C. or D.C.

For supplying power to the arc, either A.C. or D.C. may be used, depending on the metal to be welded, type of joint, and various other factors. For example, A.C. is best suited to the welding of aluminium, whereas D.C. is preferred for welding copper. In the welding of light alloys, ordinary A.C. welding sets are not entirely satisfactory, and it is recommended that a power unit specially designed for the Argonarc process should be used. In these equipments a high-frequency current of low voltage is superimposed upon the welding current; this facilitates the striking of the arc and permits the use of a longer arc during welding.

The D.C. machines are usually of the motor-generator type, and the best results are obtained where such machines are fitted with voltage control independent of the current adjustment, so that the striking voltage may be set to a high, low, or intermediate value for any desired current output. When using D.C. for manual or machine welding, the negative pole of the generator should be connected to the welding torch.

D.C. is suitable for the welding of stainless steel, nickel, and nickel alloys, and also for copper and copper alloys.

We are indebted to The British Oxygen Co., Ltd., for supplying the information upon which this article is based.

UNIONMELT AUTOMATIC WELDING

THE Unionmelt process is a method of automatic electric welding in which molten metal from a bare wire electrode is deposited on the base metal through a screen of finely divided material. This material is known as "Unionmelt" or "melt." The welding current is passed through this material, which is a highly resistant conductor, and the heat generated by the passage of the current melts the rod and the base metal. The process has its chief application in shipbuilding (see page 130 of this volume) and pressure-vessel fabrication.

The Welding Equipment

A specially designed welding head, shown in Figs. 1 and 2, can be used with currents up to 2,000 amps. A.C. It uses a coil of wire up to $\frac{5}{16}$ in. diameter. The powdered "melt" is carried in a hopper attached to the head, and is fed by gravity to the welding zone. The head is mounted on a carriage electrically driven at speeds ranging from 4 in. to 80 in. per minute.

Current is supplied to the welding head by a portable power equipment, of which there are two types: the berth type, which may be used on any location, indoor or outdoor; and the shop-type unit, which is suitable for use only inside the welding shop.

Accessories for the equipment are an automatic guiding device and a Melt Recovery unit, which picks up, by suction, the unfused portion of the powder

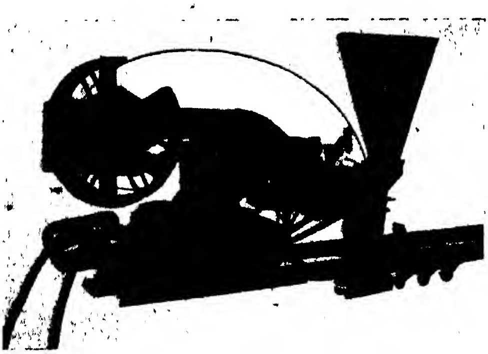


FIG. 1.—WELDING HEAD OF THE UNIONMELT EQUIPMENT

The "melt" hopper is shown on the right.

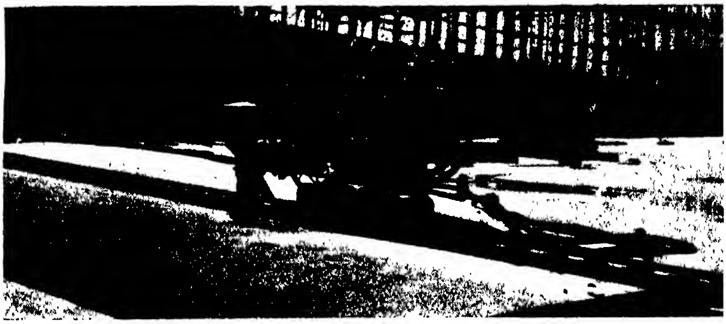


FIG. 2.—SHIPYARD WELDING, USING THE UNIONMELT PROCESS

deposited by the welding head. The powder is collected in a bin, sieved, and then re-used.

The " Melt " Material

In choosing the Unionmelt powder, which is available in three grades, it should be remembered that size 8 × 200 is a coarser powder than 12 × 200, and the latter is coarser than the 20 × 200 size. Coarse Unionmelt produces deeper penetration and narrower welds than a fine powder, which is preferable for producing quiet welding action and smooth finish.

The machine should be adjusted so that the depth of the powder applied to the weld is no greater than that necessary to produce reasonably quiet welding. A heavy burden of "melt" may produce a rough weld surface. Ideal conditions are shown by an almost continuous flame burning around the welding rod and continuous agitation of the "melt" material. The melt guide-plates should be adjusted so that the width of the layer of power deposited is about three times the width of the weld being made.

Current and Voltage Control

The U.M. voltage-control unit, which maintains the arc voltage at a steady value, is mounted on the power pack. A remote-control panel may, however, be fitted to the head, allowing the necessary adjustments for altering the current and voltage to be made at the head.

Voltage control is carried out by means of an electronic device, so that once the controls are properly adjusted, the machine will weld continuously until the electrode wire is consumed. The order of operating the controls at the start of a weld is shown in Fig. 3.

The "Rod Speed" knob governs the speed of the motor feeding the rod to the welding zone, and the dial should be turned to a speed slightly greater than that required. The flickering of an indicating lamp on the welding head

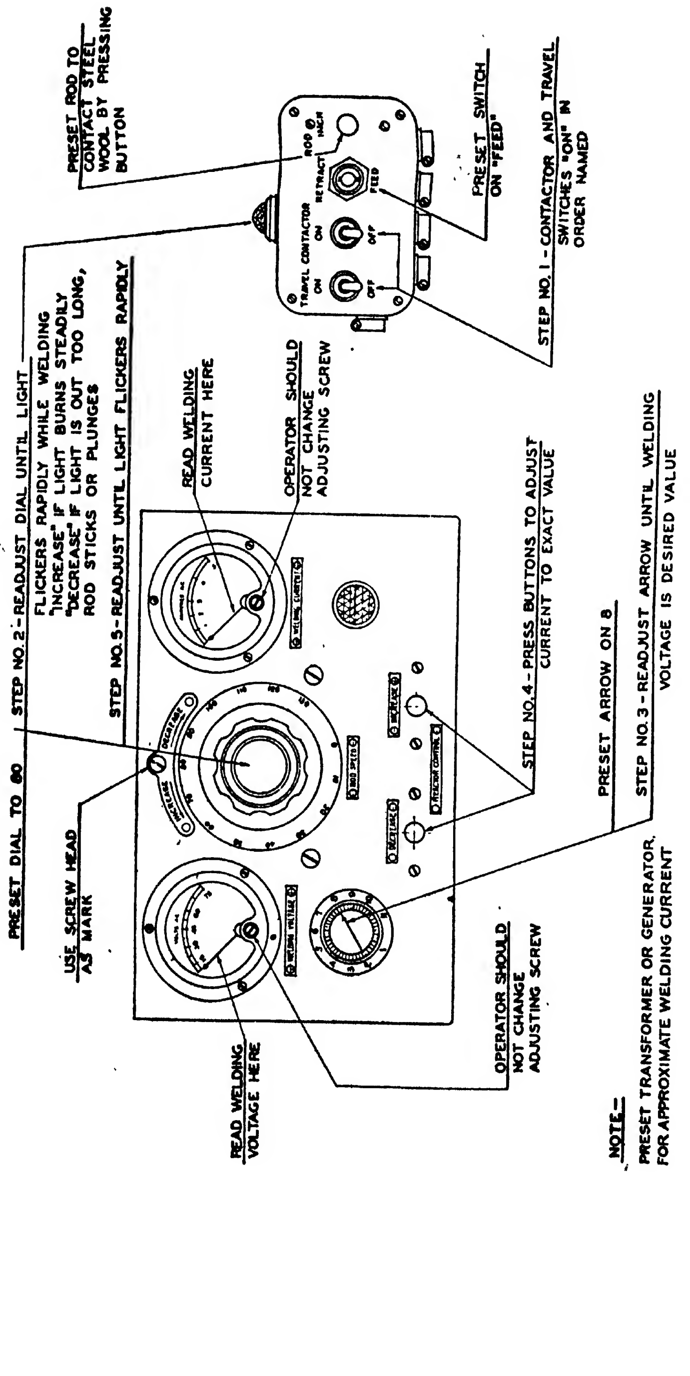


FIG. 3.—SEQUENCE OF OPERATING CONTROLS FOR UNIONMELT WELDING

indicates the action of the control. If the lamp glows intermittently, with long intervals, the rod speed knob must be set at a lower value, whilst when the lamp remains "on" all the time the setting must be increased. Correct setting of the control is indicated when the lamp flickers rapidly.

The following points should be noted when setting the controls: with a high current the weld is higher and wider, with a deeper penetration; a low welding voltage produces narrow welds, with deeper penetration than a high voltage; if the welding speed is increased from normal, the weld will have a deeper penetration and will be slightly narrower, whilst, if the speed is reduced, the weld will be higher and wider, and penetration will be reduced.

Welding Procedure

The various procedures for Unionmelt welding are given below. In all cases the parts to be welded should be cleaned by grinding or wire brushing. The plate edges should butt tightly, as any gap above $\frac{1}{32}$ in. will allow the molten metal to escape.

A COPPER-BACKED BUTT WELD.—This is used where full penetration is desired with a single run, as in the production of longitudinal welds in pipes, box-section girders, and stanchions. Copper backing is also employed for butt welding thin-gauge material. The members being welded should be firmly held down against a grooved copper backing bar, preferably by means of jigs.

TWO-PASS BUTT WELDS.—These are used for bulkheads, and many other applications.

BUTT WELD BACKED BY MANUAL WELD.—A third procedure is that of making a butt weld backed by a manual weld, deposited downhand. This technique may be used in cases where the work can be turned over, but where a tightly butting joint cannot be obtained. Weld penetration must be sufficient to ensure at least $\frac{1}{8}$ in. overlap of the two welds. The manual backing weld should be thick enough to permit the desired penetration by the Unionmelt weld, without allowing the latter to burn through. In cases where the work cannot be turned over during welding, the manual weld is deposited overhead. Both overhead and downhand manual welds are used where the overhead bead is insufficient to provide backing for the Unionmelt weld.

THE INTEGRAL BACKED WELD METHOD.—This is widely used in shipbuilding, where it can be arranged for seams between plates to be immediately above a supporting member. By this means, butt welding two bulkhead plates and attaching a stiffener may be done with only one weld. Little preparation is required for plates used for such parts.

NON-POSITIONED FILLET WELDS.—These may be made with leg lengths up to $\frac{5}{16}$ in. in one run. It is necessary to use the automatic guiding device.

Where it is necessary to connect plates to an underlying support, a plug weld may be made. The only preparation necessary is the punching or drilling of holes in the top plate.

We are indebted to The British Oxygen Co., Ltd., for supplying the information upon which this article is based.

STRESS RELIEVING OF FABRICATED WORK

IT is well known that residual stresses are contained in structures fabricated by welding, and these depend upon the restraint imposed during the welding operation, but strength is not impaired if the material and weld can behave in a normal ductile manner. Stress concentrations do, however, exist in many fabricated structures which may crack when subjected to load, unless they are stress relieved by heat treatment prior to being placed in service.

When accurate machining is required, stress relieving will prevent distortion during the operation. Certain parts of gas works and chemical equipment suffer from stress corrosion, cracking, or embrittlement caused by chemical action, and these will benefit from heat treatment. Stress relieving is most frequently performed on boilers and pressure vessels, such as those used in oil refineries, where dangerous gases and liquids may be stored at high pressures. In the manufacture of these vessels, it is essential to take every precaution against a rupture in service.

Stress Relieving Process

The heat-treatment operation known as "stress relieving" is accomplished in a furnace at a temperature of 600–650° C., which is low enough to avoid scaling and distortion of steel parts. Articles having widely varying thickness must be slowly heated, but uniform cylindrical drums and pipes can be heated at an appreciable rate. In practice, a furnace containing a charge of 40–60 tons may be heated to temperature in six to eight hours. The charge is soaked for a time sufficient to ensure that all parts actually attain the desired temperature, and it is usual to allow one hour per inch of maximum metal thickness. A fabricated metal structure having a maximum metal thickness of 4 in. would therefore be soaked for four hours in addition to the time required for heating to temperature. The rate of cooling must be slow enough to avoid temperature differences, and for large parts of non-uniform thickness cooling in a closed furnace down to 100° C. is recommended. For small and large uniform parts the time may be shortened by cooling in the closed furnace to 300° C., and then increasing the rate by taking the material from the furnace or opening the doors.

FURNACES

The cross-sectional area of a stress-relieving furnace must be large enough to take the maximum size of vessel or structure which is contemplated for the

FIG. 1.—A CHARGE OF APPROXIMATELY 40 TONS ARRANGED ON THE BOGIE OF A CAR-BOTTOM TYPE STRESS-RELIEVING FURNACE. *(Dowson & Mason Gas Plant Co., Ltd.)*

future, as the width and height cannot be modified. The length is not so important, as this can be increased after the furnace has been in service. Vessels or structures longer than the furnace can be treated in sections, one end projecting from the front, which it is necessary to seal. It will be appreciated that the disturbance and rebricking of the front seal is a nuisance, and wherever possible a furnace of sufficient length should be installed to deal with general production and given an adequate allowance for future requirements.

Operation and Fuel Requirements

However large the production, a stress-relieving furnace can only be intermittently operated because the heating and soaking periods, although relatively short (about ten hours total), are followed by a cooling period of thirty hours or more. Unloading, inspection, and recharging also require considerable time, so that a furnace which is used on a Monday may not be available again until Wednesday. The fuel requirements are therefore very intermittent, being at 100 per cent. for about six to eight hours, followed by 30–40 per cent. of the maximum demand for another two or four hours, and nothing further until the furnace is required for another charge. This intermittent operation has considerable bearing on the choice of fuel, and has led to the use of town's gas or oil fuel in preference to producer gas and solid fuel.

Bogie-type Furnaces

Three classes of furnace most suitable for stress relieving of pressure vessels and other welded work are: the car-bottom or bogie type, the sectional remov-

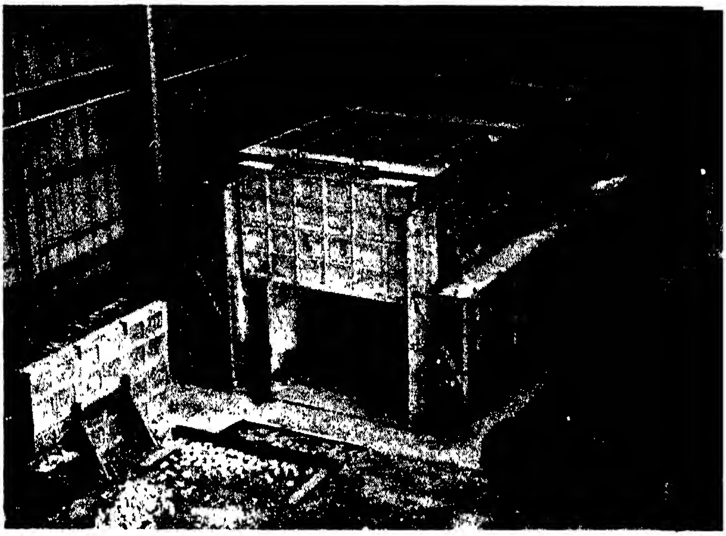


FIG. 2.—GAS-FIRED PORTABLE COVER-TYPE STRESS-RELIEVING FURNACE AT THE WORKS OF G. A. HARVEY & CO. (LONDON), LTD. (*Courtesy "Welding"*)

able roof, and pit furnaces. The car-bottom design is the most popular in this country and in the U.S.A., and is illustrated in Fig. 1. The material is laid on a refractory-topped bogie, which is pulled into and out of the furnace by an electric winch or by the shop crane.

Removable-roof Furnaces

The sectional or removable-roof furnace, as seen in Fig. 2, has a number of interesting features, of which the most important is the ability to vary the length to suit the material charged. The roof comprises removable sections, and the door can be placed in three or more alternative positions. The capital cost is somewhat lower than for the car-bottom design, since no bogie, haulage gear, rails, or wheels are necessary.

Pit Furnaces

Pit furnaces are of two classes, the first being rectangular and built below floor-level, with the top projecting about 3 ft. In this furnace the fabricated structures and vessels are placed horizontally as in the other designs, but material longer than the furnace cannot be accommodated. The second form of pit furnace is circular, and can be constructed above and below floor level, but requires the vessels or structures to be upended for loading, and necessitates an extremely high building to give adequate head-room.

Furnace Temperature

The measurement, recording, and controlling of temperature is very important, and it is desirable for records to be kept to show that a charge has been correctly treated. Thermocouples should be placed in positions which indicate the temperature of the charge and not merely furnace temperature. Those in the roof should be fitted with raising and lowering gear, as it is important, when a charge is withdrawn, that they should be pulled out of the way to prevent breakage of projections. Wherever possible the temperature should be controlled automatically in addition to being recorded, and a furnace should be divided into independently controlled zones of between 10 ft. and 15 ft. long.

WORKING SUPPORTS.—It is rather important that the method of supporting the work during the heating process does not prevent expansion of the parts. In the bottom of some furnaces refractory support piers are arranged, and these are capped with steel plates. Sometimes heat-resisting alloy stools are used which are advantageous, since they require less fuel to heat than refractory piers, and they can be moved to the most effective positions for supporting the article. The position of the stools should not, however, interfere with the circulation of gases within the furnace.

STRESS RELIEVING BY LOCALISED HEATING.—This is not recommended, as it may induce as many stresses as it relieves, but it can be practised in special circumstances where heat can be applied uniformly across a section and the unheated ends of the material are free to expand.

L. G. A. L.

ELECTRIC RESISTANCE WELDING

ELECTRIC resistance welding depends on the heating effect of an electric current, produced mainly by the contact resistance between the two pieces of metal being welded, and to a lesser extent by the resistance of the material itself.

The two portions of material to be electrically resistance welded are held together under a controlled mechanical pressure, while a heavy current is passed through the joint. The resistance of the joint, plus the resistance of the material itself, causes the intervening metal to heat up, and, if the conditions are correct, local fusion takes place.

The success of this welding process depends upon applying the correct mechanical pressure over the area where the weld is required, and upon controlling the heat and time interval so that the weld is neither "overdone" nor improperly fused.

Types of Resistance Welding

There are four basic varieties of this type of welding, known respectively as spot, seam, projection, and butt welding, and in this order they will be considered.

SPOT WELDING

This application of resistance welding is probably the best known and most generally used. The reason for this is probably that it can replace riveting without any change in the design of the article, and the manufacturer can therefore adopt the new process without undertaking any liabilities in the way of new drawings or layouts.

Fig. 1 shows the principle of spot welding, and a typical machine of the simple pedal-operated variety is shown in Fig. 2. In Fig. 1 is seen the transformer core having a primary winding (tapped at a number of points) and a secondary winding, the two ends of which are connected through massive copper or bronze arms to a pair of copper or alloy tips.

These tips impinge upon the plates or sheets to be welded together, and since the cylinder of metal represented by the portion of the sheets between the points of the two tips is of considerably higher resistance electrically, and causes an extreme concentration of current, this cylinder may be raised rapidly to welding heat without affecting the temperature of the remainder of the secondary circuit.

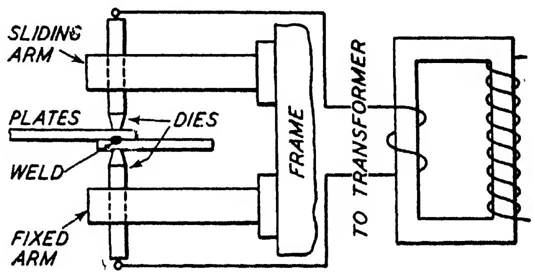
Heat Generated at Weld

The amount of heat generated will be proportional to I^2R, where I is the current flowing through the material and R is its electrical resistance. The actual figure in kilocalories will be found to be $I^2 \times R \times T \times 0{\cdot}238 \times 10^{-3}$, T being the time of weld and $0{\cdot}238 \times 10^{-3}$ the conversion factor from joules to kilocalories. The resistance to be considered in this equation will depend on many items, the chief of which are:

(1) Pressure between electrodes and the work.
(2) Size and shape of the electrodes.
(3) Electrode material.
(4) Surface condition of the sheets (whether scaly or rusty).
(5) Specific resistance of the sheet.

FIG. 1.—PRINCIPLE OF SPOT WELDING

The machine consists fundamentally of a transformer, a press, and electrodes or dies bearing on the work. The lower electrode is usually fixed, the upper being arranged to move down on to the work.



Factors Governing Successful Spot Welding

From the foregoing it will be appreciated that there are three factors to be considered in successful spot welding: (1) current, (2) mechanical pressure, and (3); time and although there is usually an optimum value for these various requirements, depending upon the price that can be paid for a machine, the output required, and the conditions of the material to be welded, they are all interdependent, and one may be varied through a fairly wide range of values without appreciable loss of efficiency in the results obtained, provided that due compensation is made in one or both of the other two.

In view of this fact, it must not be supposed that the settings advised (Table I) are the only ones to give good results in a particular gauge or type of metal. However, an attempt has been made to indicate the sizes which have been found to be the most satisfactory in practice. If these figures are departed from, it may be taken that, within reason, the larger the machine the better and more economical will be the results.

Electrical Rating

The method of indicating the rating of resistance-welding machines, which is given on the machine nameplate, is the nominal kVA, which is 50 per cent. of the short-circuit primary kVA on top tapping. The primary voltage and

TABLE I.—SPOT WELDING MILD STEEL

Top-plate Thickness		*Bottom-plate Thickness*		*Minimum Electrode Pressure*	*Top-electrode Tip Diameter*	*Bottom-electrode Tip Diameter*	*Weld Current*	*Weld Time*
In.	*S.W.G.*	*In.*	*S.W.G.*	*Lb.*	*In.*	*In.*	*Amps.*	*Cycles*
0·01	28	0·01	28	120	$\frac{1}{8}$	$\frac{1}{8}$	6,700	5
0·02	24	0·02	24	190	$\frac{5}{32}$	$\frac{5}{32}$	7,100	6
0·03	22	0·03	22	275	$\frac{3}{16}$	$\frac{3}{16}$	7,500	7
0·04	20	0·04	20	275	$\frac{3}{16}$	$\frac{3}{16}$	8,000	10
0·05	18	0·05	18	380	$\frac{7}{32}$	$\frac{7}{32}$	8,800	13
0·06	16	0·06	16	500	$\frac{1}{4}$	$\frac{1}{4}$	9,700	18
0·08	14	0·08	14	620	$\frac{9}{32}$	$\frac{9}{32}$	11,000	20
0·10	12	0·10	12	770	$\frac{5}{16}$	$\frac{5}{16}$	12,500	25
0·12	10	0·12	10	1,000	$\frac{11}{32}$	$\frac{11}{32}$	14,000	32
0·19	6	0·19	6	1,500	$\frac{7}{16}$	$\frac{7}{16}$	15,300	48
0·25	—	0·25	—	2,000	$\frac{1}{2}$	$\frac{1}{2}$	21,500	60
0·03	22	0·05	18	275	$\frac{3}{16}$	$\frac{7}{32}$	7,500	7
0·03	22	0·08	14	275	$\frac{3}{16}$	$\frac{9}{32}$	7,500	7
0·05	18	0·10	12	380	$\frac{7}{32}$	$\frac{5}{16}$	8,800	13

Electrodes.—Pure copper, with a conductivity of about 90 per cent., is not normally suitable for spot welding mild steel. The addition of a small percentage of chromium or cadmium, although reducing the conductivity by about 10 per cent., may add 50 per cent. to the hardness and considerably increase the softening temperature, prolonging the tip life. Comparative figures are given below:

	Hardness D.P.H.	*Conductivity Per cent.*	*Softening Temperature °C.*
Hard-drawn copper .	95	90	150
Cadmium copper .	110–145	85	250
Chromium copper .	150	80	500

Tip Size.—The tip diameter in all cases is calculated as the square root of sheet thickness in inches. The mushrooming of the tip caused by successive operations reduces the current density of the weld. To keep this effect to a minimum, and to increase the operations between redressing, an included angle of not less than 120° is recommended.

Electrode Force.—Should be such that the pressure is not less than 10,000 lb. per square inch.

Pitch.—The minimum pitch at which spots can be made without the shunt effect becoming too serious is 3 × Weld diameter.

Edge Distance.—Minimum edge distance should be 1·5 × Weld diameter.

primary current, which is the short-circuit primary current on top tapping, is also shown on the nameplate.

The most practical method of indicating the power required to effect a given spot weld is to express it in terms of secondary current, which is the

actual welding current given as a guide in Table I. The secondary current and the minimum duty cycle are always quoted to the user, although not necessarily on the name-plate.

Some confusion may arise as to the difference between kVA and kW. The kVA should be known in order that the size of cable required, and the effect on the mains, may be determined, whereas the kW is the measure of effective "power to do work" available in the machine.

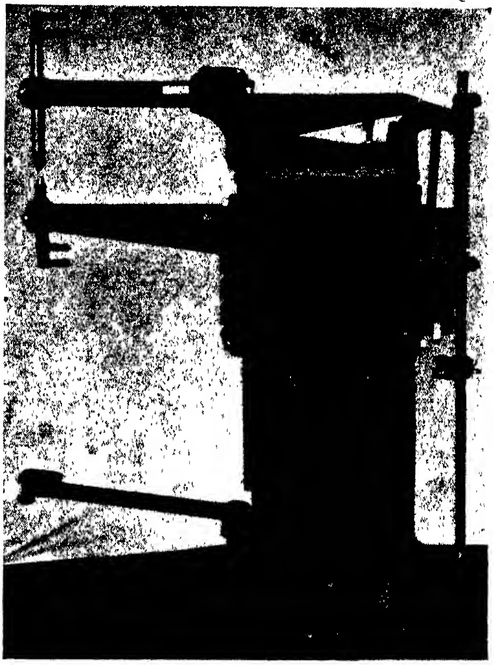


FIG. 2.—PEDAL-OPERATED SPOT WELDER WITH TOGGLE MECHANISM FOR INCREASING WELDING PRESSURE

Showing position of toggle when welding points are open. (*Holden & Hunt, Ltd.*)

Efficiency of Machine

The connecting link between kVA and kW, known as the power factor, is $\frac{kW}{kVA}$, and is a measure of the efficiency of the machine. This efficiency depends partly upon the type and design of the transformer and partly upon the length of the arms of the machine, and the distance they are apart.

If a machine having a 12-in. arm and a 12-in. throat is taken as a standard, there are machines on the market varying in power factor from as high as 0·9 to as low as 0·4 or 0·5. This means that, although both welders are of an equivalent effective capacity of, say, 10 kW, one would be rated at 11 kVA and the other at 20 or 25 kVA.

The drop in efficiency caused by the length of arm and distance between the arms, however, is outside the control of the manufacturer, and all makes suffer equally from this defect.

When steel or iron, both of which are magnetic materials, are being welded, such metal as is inside the throat of the machine will considerably increase the losses experienced, and with this material it is found that an increase in arm length of 6 in. will necessitate an increase in the kVA of the machine of about 25 per cent.

TABLE II.—SPOT-WELDING ALUMINIUM ALLOY SHEET

Thickness of Material In.	*Cycles**	*Time Secs.*	*Welding Current Amps.*	*Electrode Pressure during Welding Lb.*
0·022	1	$\frac{1}{50}$	17,000	300–500
0·036	2	$\frac{1}{25}$	21,000	400–650
0·048	3	$\frac{3}{50}$	23,000	450–700
0·064	4	$\frac{2}{25}$	26,000	500–800
0·080	5	$\frac{1}{10}$	29,000	600–900
0·128	8	$\frac{4}{25}$	36,000	700–1,200

* Based on 50 cycles per second.

The actual "set up" of a machine is best made experimentally for any particular article, but Table II gives a fairly accurate basis on which to prepare the settings of time, welding current, and mechanical pressure for various thicknesses of aluminium-alloy sheet.

Little variation of time or current is necessary for the welding of different alloys, but, generally speaking, greater mechanical pressures are to be recommended for welding the harder high-strength alloys.

TABLE III.—STRENGTH OF SPOT-WELDED JOINTS IN ALUMINIUM ALLOY SHEET

Material	*Thickness In.*	*Number of Spots*	*Average Strength Lb.*	*Efficiency Per cent.*
NA.2SO	0·050	2	420	68
NA.51SW	0·050	2	775	46
NA.17ST	0·050	2	880	29
"Alclad" NA.17ST	0·050	2	910	32

Primary and Secondary Current

The kVA capacity given on the nameplate of the machine allows the amperage on the primary winding to be calculated, and it may also easily be measured, but the current in the secondary circuit is of such a magnitude that few factories are equipped with instruments by which it may be recorded. For those who are interested, however, it may be said that this figure is usually between 100,000 and 200,000 amps. per square inch, the open-circuit voltage varying between 1 volt for light work and about 10 volts on heavy jobs where considerable resistance has to be overcome, or on machines having exceptionally long arms where a large voltage drop is experienced when the circuit is closed.

Mechanical Pressure Applied

The mechanical pressure which is applied to the weld is of considerably greater importance to the efficient working of a machine than is often realised, and it is only recently that much attention has been paid to this factor.

Why Effective Pressure is Required

Effective pressure is needed: (1) to ensure that the two or more pieces of metal to be welded are brought together firmly at the point of weld; and (2) so that there is not a point of high electrical resistance between the electrode tip and the sheet; this causes undue heating and rapid wear of the tip, and surface heating and a burnt and unsightly depression on the sheet; (3) to forge the weld and to force out scale and absorbed gases from the joint. The process of forging consists of deforming the crystals and allowing them to re-form by growing across the boundary that separated the two sheets.

Variation in pressure will upset the balance of conditions arranged for, and it is therefore desirable that when settings for any particular job are recorded, some arrangements should be made for recording the pressure employed.

Types of Machines in Use

The machines may be pedal operated through a spring (see Fig. 2), and while these will ensure that an equal pressure is applied, provided that the pedal is depressed to the same point each time, the operator cannot be depended upon to do this, nor is there any easy method, other than counting the turns on the adjusting hand wheel, of knowing the amount the spring is compressed, or what such compression means in terms of pounds per square inch at the electrode tips.

Compressed-air-operated Machine

The tendency to-day, therefore, is to discard the pedal-operated welder in favour of a machine operated by a compressed-air cylinder having a reducing valve and pressure gauge whereby the exact pressure applied can be recorded and returned to unfailingly. As an alternative arrangement, motor-driven spot welders are employed, and whilst these do not as a rule show any advantage over the pedal-operated models as regards the recording of pressures, they do at any rate ensure that the spring is compressed to the same extent in the making of each weld.

The correct pressure to be used varies considerably according to the type of metal to be welded.

Fully Automatic Control

On the fully automatic machine a vertically sliding head applies a predetermined pressure for a controlled time as low as 5 cycles ($\frac{5}{50}$ sec.) with contactors, and half and fractions of half-cycles ($\frac{1}{100}$ sec.) with electron-tube devices. On such machines, and of those machines approaching this type, the responsibility of sound welds being obtained continuously is removed from the operator and placed in the hands of a welding engineer, who can issue set-up instructions which may be repeated with unfailing results. In order that resistance welding may find its proper place in industry, it cannot be emphasised too strongly that fully automatic machines should be installed.

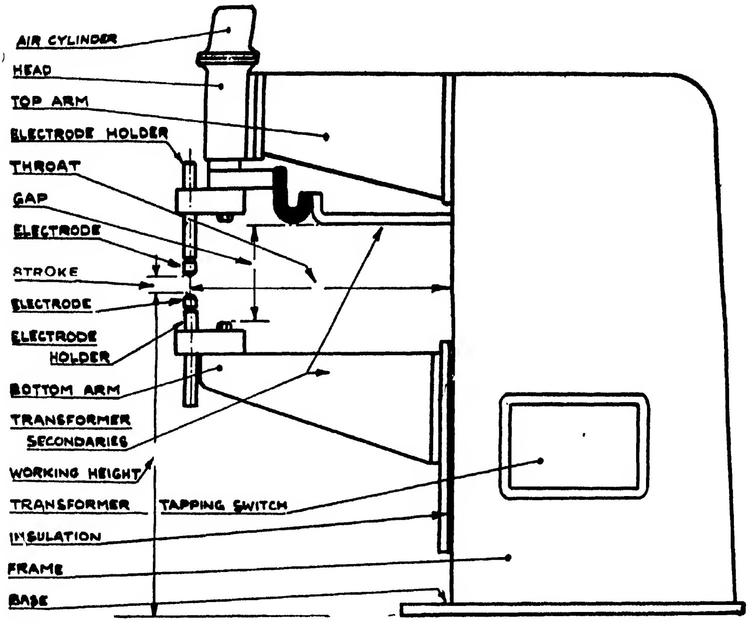


FIG. 3.—DIAGRAM SHOWING COMPONENT PARTS OF A MODERN SPOT WELDER

The Modern Machine

Fig. 3 shows an outline of a modern spot welder and its various parts.

The throat of the machine should be such as to allow easy manipulation of the work to be handled, but not too large (i.e. 20 in. and over), otherwise the kVA capacity will require increasing. The gap of the machine should be kept between 12 and 18 in.; the same remarks apply here as for throat dimensions.

The stroke is dependent to a great extent on the welded assemblies, but should not be excessive, as this will mean wasted energy and probably increased maintenance. A reasonable stroke dimension for spot welders is 2 in., and from 2 in. to 4 in. on projection welders.

Speed of Machine (Strokes per Minute)

The speed of the machine will be governed by the class of work. Repeating machines will not be necessary for single-spot welds or projection welding. For continuous spot welding, speeds of 150–200 strokes per minute on air-driven machines are quite common, and up to 300 strokes per minute for motor-driven equipments, but special care must be taken on high-speed equipments regarding the control.

(*Note*.—Three hundred strokes per minute $= \frac{60 \times 50}{300} = 10$ cycles per complete stroke. Assume the electrodes are closed 50 per cent. of this time, then the welding time cannot exceed 3 or 4 cycles. As this is a short time for accurate contactor control, ignitron control is to be recommended.)

Light-duty Welding Pliers

For spot welding light-gauge work up to 26 S.W.G., simple manually operated pliers of the type shown in Fig. 4 can be used. For this light work, water cooling of the electrodes can be omitted so as to keep the movable part of the equipment as light as possible.

For heavy-duty work, where continuous operation is likely to be required, and for spot welding heavier gauges, it is essential to have the electrodes power operated and properly water cooled.

Light-pattern pliers are very useful for tacking operations prior to the full-strength welding being carried out. They enable the various components of an assembly to be located and checked for accuracy of position, especially where production assembly jigs are not available.

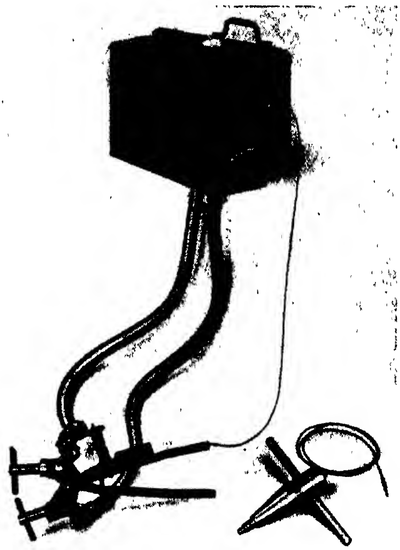


FIG. 4.—A LIGHT-PATTERN PORTABLE SPOT WELDER
Mechanical pressure is manually applied. (*Buck & Hickman, Ltd.*)

TIMING AND CURRENT CONTROL

Timing Apparatus

The development of timing apparatus for spot-welding machines has probably progressed farther than any other department of resistance-welding science, and apparatus is available to-day to cover all possible conditions.

The experiments conducted in this direction have done more than anything else to change spot welding from a "hit-or-miss" process to a precision operation.

In the early days of the industry (and there are still machines in use to-day operating on this principle) the timing of the weld was left entirely to the judgment of the operator.

He brought his electrodes together, closed the welding circuit by a further depression of his pedal, and kept it closed until he considered that a weld was made.

The first improvement was in the fitting of a dashpot to the switch, whereby it only remained closed for a predetermined time; but whilst this arrangement worked excellently on absolutely clean material, it failed on scaly sheets, since it may take an appreciable time before the weld proper begins for the current to break through the high-resistance coating.

The Current Controller

The next stage in the development was the current controller, and for general-purpose work some modification of this arrangement is the most useful type of control in use to-day. It depends for its action upon the fact that there is a sudden surge of current as the two sheets of metal fuse together and the resistance of the joint is removed. This surge, which cannot occur until a weld has been made, is utilised to open the switch controlling the welding current.

A somewhat similar apparatus is the voltage-drop control which depends for its operation on the drop in potential difference between the electrode tips, again at the moment of fusion between the sheets.

Another useful arrangement which was put on the market at about the same time as the two previous control gears is that which operates by measuring the watt-seconds consumed. This equipment has the advantage of not being affected by variations in power factor, but it lacks the simplicity of the current control.

Modern Timing Apparatus

The final development in welder control gear has shown a return to the pure time control. It has the advantage of absolute accuracy, made necessary by the more rapid welds now being made and the unstable alloys which have to be welded. Its use has been made possible for the ordinary run of work by the fact that better, cleaner, and more consistent material is now available.

The original dashpot controller was a very crude instrument, whereas modern timers, employing grid-controlled valves of the hot-cathode or mercury-pool types, can reduce the welding time to a fraction of a cycle (less than $\frac{1}{50}$ sec.) and can even select the same portion of the cycle every time.

Simple Valve Timer

In the simplest form of valve timer a vacuum- or gas-filled valve is used, and a condenser is kept charged between welds to a definite value through an adjustable resistance. It is then discharged, holding the contactor switch in for a predetermined time.

Another type employs a second transformer, connected in series with the welding transformer, and this is short-circuited by large hot-cathode mercury-vapour valves when the weld is to be made. During the "off" periods this transformer acts as a choke, and only a very small residual current is allowed to flow.

The third type consists of two grid-controlled mercury-pool bulbs, connected in parallel inverse relation, which handle the primary current of the welder

direct, and are able to provide welding times between ½ cycle and 2 or more seconds.

Welding Pressures for Different Metals

All mild-steel sheet work should have heavy pressure, both at the start and finish of the weld, and be done as quickly as the machine's power will allow, although a few seconds must be given to thicker sheets to let the heat "soak." If *undue* flashing of sparks occurs at the weld, the balance of pressure against secondary voltage is incorrect, the pressure is too low or the voltage too high. This is more applicable to clean sheets, as scaly plates will always flash a good deal.

A trade saying is that "pressure subdues heat," which is convenient to remember.

Galvanised, tinned- and lead-coated sheets are often regarded as difficult spot-welding propositions, but they are quite satisfactory—given the correct pressure cycle and an efficient electrical system of ample capacity. A light pressure is required on the weld at the start, and this must increase rapidly during the heating period to a heavy finishing pressure. A light pressure gives a higher contact resistance, which melts the coating in between the sheets, and the heavy following pressure squeezes the greater part of it away from the forging surfaces of the weld.

The same technique applies to non-ferrous materials—brass, aluminium, nickel, bronze, etc. The light alloys and copper require machines of large size and special design.

Regulation of Welding Current

The transformer tappings are usually connected to a series of sockets protected by a shield. The first tapping gives the highest secondary voltage and welding current when the plug is inserted. Always use as high a voltage as the job and pressure permit and as will do the weld in the shortest time. Mild steel above about 12 S.W.G. should be given time for the metal to soften around the actual weld, enough to allow proper forcing together of the weld area. If during this period the metal melts and possibly spurts past the contact point, then the current is excessive or the pressure insufficient.

Stainless, carbon, and alloy steels usually work better on lower secondary voltages.

From what has just been said about coated sheets and non-ferrous metals, it will be obvious that high current values are needed to compensate for their better conductivities of heat and electricity. The thickness of such materials which a given size of spot welder will handle is 25–75 per cent. of its capacity in steel.

Timing of Weld with Foot Control

With ordinary foot control, the weld should be executed in one straight stroke to the floor without a pause, taking a fraction of a second longer with

thicker materials up to 12 S.W.G.; above which a slight pause for "heat soak" should be made in the middle of the stroke and the pedal held down for a couple of seconds while the weld cools.

Coated and non-ferrous materials require a slow initial movement of the pedal, so that the pause (if needed) occurs when the pressure is light. This is followed by a quick finish to the stroke.

Operating Automatic Machine

The operations on an automatic spot welder generally conform to the following sequence:

(*a*) Position work and depress the foot pedal.

(*b*) Head descends on work and the pressure between electrodes increases to a preset value.

(*c*) *The welding current is caused to flow by a relay closing at a prearranged electrode pressure.*

(*d*) The duration of the welding current will be preset and controlled by contactor, thyratron, or ignitron devices.

(*e*) The electrodes will remain closed for a short duration to allow the welds to cool under pressure. (The forging duration varies directly to the added thickness of material being welded.)

(*f*) Pressure is removed and the electrodes caused to open.

(*g*) If desired, electrodes will reclose when foot pedal is held down, causing the above sequence to be repeated.

ELECTRODES

Water Cooling

It is essential that the contact points of all spot welders—with the exception perhaps of small wire-working machines and portable welding pliers—be

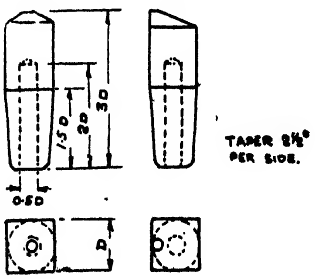


FIG. 5 (*above*).—CENTRE-TIP AND OFFSET-TIP ELECTRODES

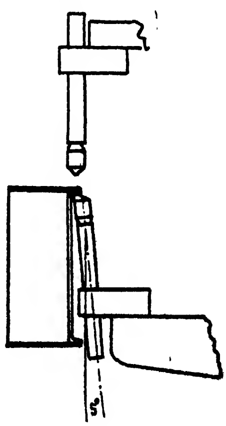


FIG. 6 (*right*).—A USEFUL METHOD OF AVOIDING A CRANKED ELECTRODE IS TO TILT THE ELECTRODE HOLDER SOME 5°

supplied with running water. Apart from prevention of overheating, a cool point has an important effect in keeping the surface of the work at a lower temperature than the core of the weld, thereby improving both strength and appearance.

The amount of water required ranges from 8 gallons per hour at 2 kVA to 50 at 25 kVA. This must be circulated by pressure from the factory supply or a small pump of the type used for suds in machine tools, coupled to a 10- or 20-gallon tank. The thermo-siphon method will not work.

In the case of small sizes of electrodes, considerable savings will be realised on electrode replacements by using one of the copper alloys specially made for resistance-welding electrodes.

Electrodes are of many shapes and sizes, the most common being the centre and offset type, shown in Fig. 5. Cranked or swan-necked electrodes are to be avoided wherever possible, as they are high in initial cost and maintenance. A useful method of avoiding a cranked electrode is to tilt the electrode holder some 5°, as shown in Fig. 6.

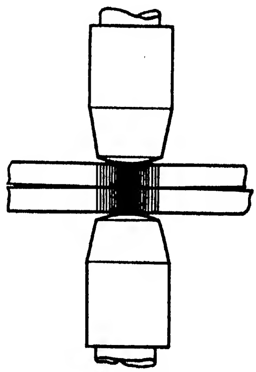


FIG. 7.—ELECTRODE TIP FACE
A spherical working face on the electrode tip is preferable to a small flat face.

Electrode shanks are also very important, and there are two types in common use, screwed and taper. Screwed electrodes are not so flexible as tapered, inasmuch as an offset tip will not screw up to the same degree of tightness, and compensation cannot always be obtained on the holders. Screwed electrodes are also troublesome with heavy currents, being liable to become welded into the holder, probably due to a speck of dirt preventing a proper seating. Taper electrodes prove very satisfactory in service, especially if dissimilar materials are used for electrodes and electrode holders. British Standard Specification No. 807 (1938) deals with tapered electrode shanks of 2½° per side, and these can be recommended. No leaks or difficulty in removing should be experienced, and they will withstand a fair share of ill-usage.

Electrode Tip Face

The use of a small, flat working electrode face is better avoided, because a spherical face gives a wider latitude to the operator, and on thick material there is no tendency for an overheated spot to spurt metal past the edge of a flat face. This spherical radius should not be too short; a suitable proportion is shown by Fig. 7, and the diameter of face should not be kept small unless necessary to clear some part of the work. Attention to these details will greatly increase the working life of the tips.

It may be remarked here that a depression in one or both of the sheets is essential to get a good weld. Marking may be avoided on one side by the use of a large flat contact, but a depression must be put in the other sheet. Actually

FIG. 8.—STANDARD STITCH-WELDING MACHINE

A pneumatically operated machine employed for stitch welding refrigerator cases.

the "flat" for this work should be just sufficiently spherical to ensure that the pressure is concentrated beneath the opposite contact point.

Setting the Contact Points

The shape of these points having been determined, they should be adjusted so that the direction of pressure is normal to the surface of the work, while the places of contact on each side of the work are directly opposite. When operating, the machine should be allowed to take its own grip on the job without restriction.

A large number of arms and special electrodes are available to deal with different jobs.

Stitch Welding

Stitch welding is obtained by operating a spot-welding machine continuously at high speed. The spot welds overlap one another to form a continuous seam.

The main advantage of this method over the roller type of seam welding machine lies in the fact that it is applicable to irregular and awkward shapes, and in confined spaces and blind corners where a seam-welding wheel is not accessible. In addition, a good-class stitch welder can be purchased for approximately 30 per cent. of the cost of a seam welder of equal quality. Where the nature of the work allows for long straight runs, however, roller seam welding is much quicker.

As in practice stitch welding produces in sheet metal a result similar to that of a flash-butt weld, but in fact much cleaner, it has found considerable application as a means of making up odd-shaped blanks, etc., and salvaging what might otherwise be scrapped material.

Stitch welding differs from spot welding, which consists of local joining together of two or more sheets of metal as a structure, inasmuch as the stitched joint is water- and gas-tight.

A typical and popular application which calls for a gas-tight joint is the manufacture of such articles as electric cooker ovens and refrigerator interiors.

"Mash" Stitch Welding

"Mash" stitch welding is the arrangement, shown in Fig. 9, of starting with the metal overlapped approximately $\frac{1}{16}$ in. and squeezing to a flush face.

Another example of "mash" stitching is shown in Fig. 10. In this case it is necessary to join edgewise two steel sheets on to a channel or angle. To produce an even flush face, which would also be watertight, having regard to the fact that the edges of the sheets may not be exactly parallel, a length of wire a little larger in diameter than the gap between the sheets is run the length of the weld and mashed flat. In this case the bottom electrode is more in the form of a table or support, while the top electrode takes the usual shape.

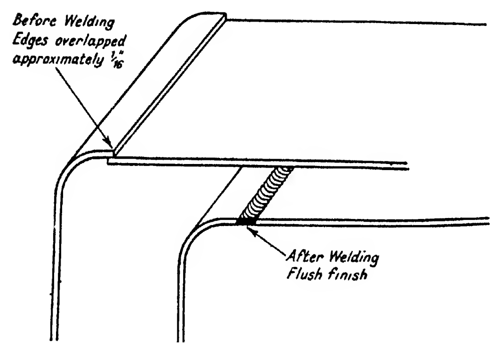


FIG. 9.—"MASH" STITCH WELDING

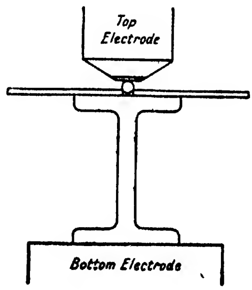


FIG. 10.—WELDING TWO SHEETS TO ANGLE OR TABLE

Bottom electrode is in the form of a block or table.

Fabricated Steel Door

A section through the edge of a fabricated steel door, which has been produced in large quantities, is shown in Fig. 11.

Here the door is composed of two outer panels folded at the edges at 90°, inside which is placed a channel to act as a stiffener and on which to weld the two panels. The bottom electrode consists of a copper bar, the upper electrode again being of standard shape. This method of construction results in a very strong and clean assembly, economically produced.

Containers

A further example typifying the usefulness of stitch welding is shown in Fig. 12. Here is a container body which, owing to its peculiar shape, could not be welded by roller seam welding. It is an easy matter to produce a gas-tight joint on this job at a speed of 20 in. per minute.

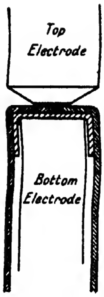


FIG. 11.—STITCH WELDING STEEL DOOR

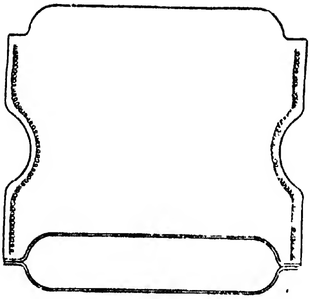


FIG. 12.—STITCH WELDING CONTAINER

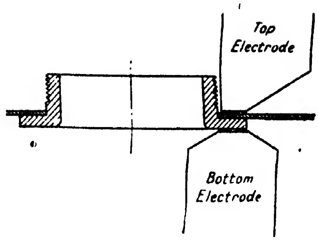


FIG. 13.—FILLER-CAP REINFORCEMENT STITCH WELDED IN STEEL TANK

Filler Cap in a Steel Container

A further interesting example is shown in Fig. 13. Here is a reinforcement for the filler cap in a steel container. The reinforcement was welded in, of course, before the ends were fitted to the tank. The welding time here for a 3-in. diameter boss was approximately 30 seconds.

One-piece Blanks

In Fig. 14 is shown a typical instance where an awkward-shaped blank was built up from two pieces of sheet steel, cut on a guillotine, and mash-welded together. It can be visualised that there are a great number of such cases, where to produce a one-piece blank would call either for expensive blanking tools or complicated cutting, and where the scrap, after blanking from a large sheet, would be considerable.

The Machine Required

At first sight it would appear that the objective in designing the machine would be the fastest possible speed, and therefore the maximum number of spots per minute. Working on this theory, machines capable of making up to 300 spots per minute have been manufactured. It was found, however, that there were drawbacks to these high speeds.

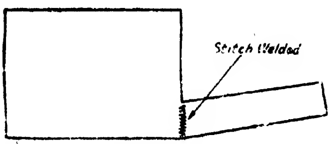


FIG. 14.—MAKING UP AN AWKWARD-SHAPED BLANK FROM SMALL PIECES OF METAL BY STITCH WELDING

The very short welding times available with the high speeds called for considerable heat which produced splashing or "spears." Moreover, it was found difficult to synchronise the current flow with the mechanical pressure and so avoid burning

on the face of the metal. In either of these cases it became necessary to clean the job after welding, by grinding or polishing—a costly operation.

A theory which has of recent years improved the quality of spot welding was successfully applied in this case. Pneumatically operated machines were introduced, designed to provide heavy mechanical pressure between the electrodes.

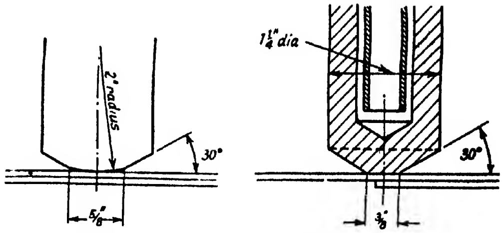


FIG. 15.—ELECTRODE FOR "MASH" STITCH WELDING
Top and bottom electrodes exactly the same.

Piloting the bringing in of the main welding contactor was a pressure switch, which operated from the built-up air pressure in the cylinder head, and so prevented the welding current being applied before the mechanical pressure had been established. Similarly, the contactor must be broken before the electrode can come apart, a positive assurance against "arcing."

It was also found that the time for which the welding current should flow was very much better as a measurement of volts-amperes-seconds than a purely time factor, inasmuch as the varying overlap set up an inconsistency in resistance between the electrodes, which was only successfully overcome by the compensating current control.

The later tendency has been to make the welding time a larger percentage of the complete cycle, reducing the number of spots per minute possible to 150–180. What would otherwise have meant a reduction of production speed has, however, been offset by the use of electrodes providing a larger area of weld per stroke. Whereas with the very high-speed machines it was considered necessary to reckon on 8 spots to the inch, with the larger area of electrodes, 6, and even 5, spots per inch have been found sufficient to produce excellent work.

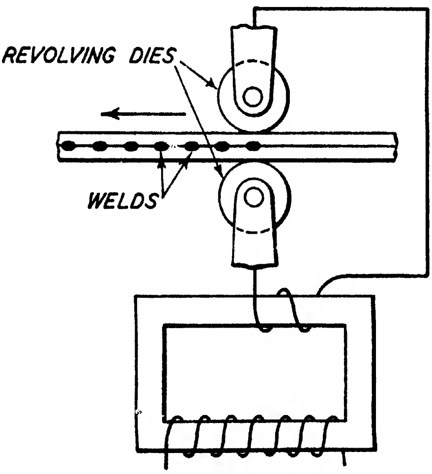


FIG. 16.—PRINCIPLE OF LAP SEAM WELDING
The revolving electrodes or dies traverse the length of the lapped plates and produce a series of intermittent or overlapping spot welds on the work.

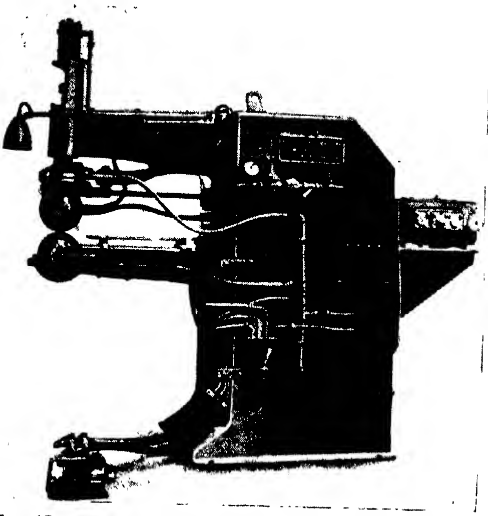


FIG. 17.—AIR-OPERATED SEAM WELDER WITH INTERCHANGEABLE TYPE HEAD

Notice that the lower wheel is enclosed in a trough to permit external water cooling. (*A-1 Electric Welding Machines, Ltd.*)

The Electrodes

A considerable number of electrode shapes have been experimented with to secure the best finish on the work, consistent with economical maintenance. Fig. 15 illustrates in two views the shape of electrode found by experience to give the best results. This design, if efficiently water-cooled and made in one of the alloys of high Brinell hardness, will give a long working life.

SEAM WELDING

In general, the seam welder differs only from the modern press-type power-driven spot welder in that its electrodes instead of taking the form of points for "spotting" are of disc or roller form. The discs are usually motor or power driven, and rotate whilst gripping the work, which is either continuously or intermittently welded (see Figs. 16 and 17).

In contrast to the various methods of fusion welding of a seam, when electrical resistance welding is employed, the edges of the two sheets must overlap, so that the welding heat can be developed at the interfaces.

Seam welding is the best practical method of resistance welding where long water- and gas-tight seams in sheet-metal articles are needed. Even when watertight joints are not required, seam welding is generally to be preferred to spot welding for uniting long seams which have no mechanical irregularities, as the continuous movement provided by the wheel electrodes gives faster production and permits better control over the work while it is in the machine.

Seam welding is mainly confined, in the case of steel, to fairly thin stock; that is to say, it is not employed frequently for sheets of a thickness greater than ¼ in. Welding speeds vary with the sheet gauge, for example ¼-in. material on a normal machine is capable of being successfully welded at 5–10 in. per minute, whilst thin sheet of the order of, say, 0·028 in. can be welded at a rate ten to twenty times as great. Special machines cater for much greater speeds. Table IV gives typical machine settings for seam welding mild-steel sheets.

TABLE IV.—SEAM WELDING MILD STEEL

Sheet Thickness		*Electrode Wheel-face Width*	*Pressure*	*Timing*		*Speed*	*Spots per In.*	*Minimum Overlap of Sheets*
S.W.G.	*In.*	*In.*	*Lb.*	*Cycles "On"*	*Cycles "Off"*	*In. per minute*		*In.*
24	0·022	$\frac{5}{32}$	500	1	$\frac{1}{2}$	144	14	$\frac{5}{16}$
22	0·028	$\frac{3}{16}$	600	1	1	120	$12\frac{1}{2}$	$\frac{3}{8}$
20	0·036	$\frac{3}{16}$	650	1 2	1 2	120 72	$12\frac{1}{2}$ $10\frac{1}{2}$	$\frac{7}{16}$
18	0·048	$\frac{1}{4}$	750	2 3	2 2	72 60	$10\frac{1}{2}$ 10	$\frac{1}{2}$
16	0·064	$\frac{1}{4}$	800	3 3	2 3	60 48	10 $10\frac{1}{4}$	$\frac{1}{2}$
14	0·080	$\frac{1}{4}$	900	4 4	3 4	45 40	$9\frac{1}{2}$ $9\frac{1}{2}$	$\frac{9}{16}$
12	0·104	$\frac{9}{32}$	1,000	5 5	4 5	36 33	$9\frac{1}{4}$ 9	$\frac{9}{16}$
10	0·125	$\frac{5}{16}$	1,200	5 6	5 6	36 30	$8\frac{1}{2}$ $8\frac{1}{4}$	$\frac{5}{8}$

PROJECTION WELDING

Projection welding, used for sheet-metal assembly, may be regarded as a mass-production form of spot welding. Technically it is a cross between spot welding and butt welding. It is a process used mainly to weld together sheet-metal parts on which suitable projections have been raised at the locations where the welds are required. It is also a useful process to use for assembling bushes and other like projections to sheet-metal parts, which could not be welded in place by spot welding, on account of the unsuitable shape of the parts at the points to be welded.

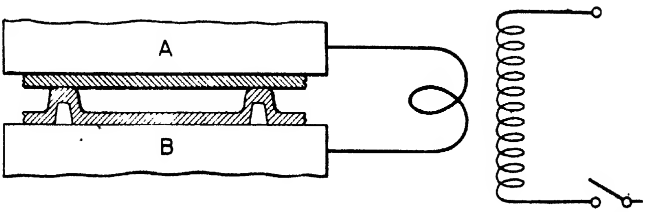
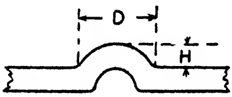


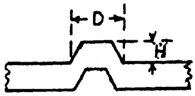
FIG. 18.—ILLUSTRATING THE PRINCIPLES OF SHEET-METAL PROJECTION WELDING

A and *B* are the platens of the machine. These are connected to the ends of the machine transformer secondary winding.



S.W.G.	D	H
14	·2″	·05″
16	·17″	·05″
18	·15″	·04″
20	·125″	·04″
22	·125″	·03″
24	·10″	·03″

FIG. 19 (*left*).—SHAPE OF PROJECTIONS ADVISED FOR THIN SHEET



S.W.G.	D	H
12	·17″	·05″
10	·17″	·06″
8	·19″	·07″
6	·25″	·07″

FIG. 20 (*right*).—SHAPE OF PROJECTIONS ADVISED FOR THICK SHEET

How a Projection Weld is Made

In Fig. 18, *A* and *B* are the upper and lower platens of a resistance welding machine. These two platens, which are large enough to embrace all the projections to be welded at the same operation, are connected to the ends of the secondary circuit of the machine transformer, so that when the circuit is completed by the upper platen being lowered on to the work, the welding current will flow through each projection point.

The work is therefore placed in position on the lower platen, and on depressing the operating pedal of the machine the upper platen descends and applies the correct mechanical pressure to ensure correctly forged welds. As soon as the pressure has been applied, the welding current is switched on by controls in the primary circuit of the machine transformer, the technique used for simple spot welding. As the steel at the projection areas heats up, the projections collapse and union takes place at all points simultaneously. At this instant the current is switched off and the platen recedes to free the work.

It will be seen therefore that the projections are used for the twofold purpose of locating the welds and for speeding up the process by making it possible to perform several welds at once. In actual practice most time is saved by the automatic location of the welds.

The shape and size of projections are important, and the figures given in Figs. 19 and 20 will be found most suitable.

BUTT WELDING

In electric resistance butt welding, the two parts to be welded are brought into contact end to end, and the joint faces are heated up by passing a suitable heavy current through the joint. The principle of producing the weld heat mainly by the electrical resistance of the joint faces is basically the same as in other forms of resistance welding, except that the electrodes are in the form of powerful vice clamps; these support the members being welded and serve also to convey the forging pressures to the joint.

TABLE V.—BUTT WELDING MILD STEEL

Diameter of Stock or Equivalent Cross-sectional Area in In.	*Maximum Power required in kW*	*Units per 100 Welds*	*Seconds per Weld*
0·036	0·75	—	0·5
0·064	1·0	—	0·75
0·125	1·5	0·03	1·0
0·25	5·0	0·1	3·0
0·5	8·0	1·0	7·0
1·0	12·0	12·0	20·0
1·5	35·0	60·0	35·0
2·0	60·0	125·0	45·0
2·5	90·0	140·0	60·0

There are two types of butt welding. The first type may be termed straight butt welding. In this process the two parts are clamped into the machine and the ends are brought together under a reduced pressure at the commencement while the current is passed through the joint to heat it up. This pressure is sufficiently high to prevent flashing. At a predetermined point the pressure is increased to forge the weld; then the current is cut off.

By far the most useful and widely used process is flash-butt welding, or just flash welding, as it is called for short. There seems to be no practical limit to the area which can be welded by this method. Machines up to 500 sq. in. weld area and of 10,000 kVA single-phase have been made.

FLASH WELDING

In flash welding there is no need for the parts to be a good surface fit, so that if the ends of the work where welding is to take place are irregular, there is no need for accurate machining prior to welding. The process itself is carried out by first bringing the parts together under a modest pressure so that the body of the materials can follow up as the joint burns away and heats up. It is during this initial period of low mechanical pressure that the flashing away of

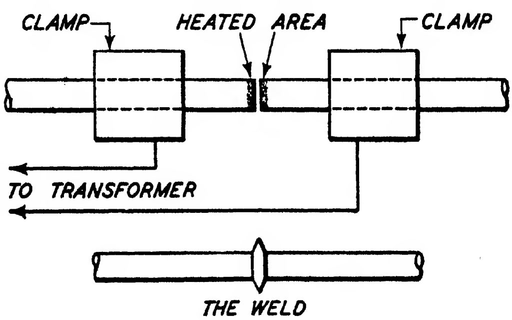


FIG. 21.—PRINCIPLE OF FLASH WELDING

The parts to be joined are clamped strongly and are brought close enough together to create an arcing effect. So much heat is developed as to melt the ends of the pieces to be joined. The current is then switched off and the parts are quickly pushed together. The molten metal is forced to the outside, bringing together the metal behind it which is in a plastic condition.

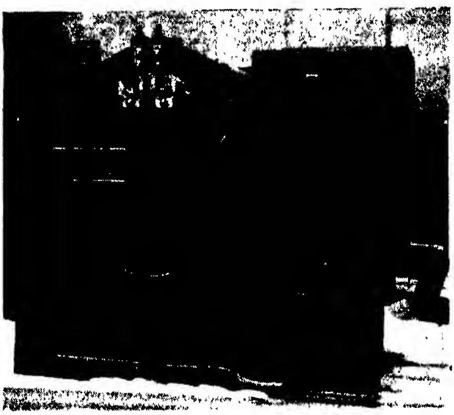


FIG. 22.—FULLY AUTOMATIC FLASH WELDER FOR JOINING THE ENDS OF CYCLE AND OTHER LIGHT-SECTION WHEEL RIMS

This machine is capable of welding up to 600 wheels per hour. (*A-1 Electric Welding Machines, Ltd.*)

the ends takes place. When a predetermined interval has elapsed, the flashing period is terminated by increasing the pressure so that the weld is forged together. Coincident with the application of the final forging pressure, the welding current is cut off (see Fig. 21).

In this flash-welding process the heating of the joint is brought about mainly by the combination of the electrical resistance at the joint faces and the arcing effect produced by the irregularities in the fit of the joint faces, coupled with the low applied mechanical pressure.

Flash-butt welding is carried out in two ways. The first, where the joint is kept in contact the whole time the process is in operation, has just been explained. In the second method the process is effected in stages. This is done either by hand control or automatically. The joint is heated up in one or more stages by first applying flashing pressure to the joint and then separating it before the weld temperature is reached. This may be repeated several times, depending on the type of work and the capacity of the machine in relation to the size of the joint.

By adopting this interrupted or preheating process, it is possible to increase the maximum capacity of a machine, as the preheating operations reduce the final kVA needed to raise the joint to weld temperature. It is an expedient also adopted for larger work, especially where undue irregularities of section are to be welded, as it gives the whole of the joint areas an opportunity of reaching the welding temperature without the risk of overheating the thinner sections, and it reduces the possibility of underheating the heavier sections.

Applications of Butt and Flash Welding

The majority of industrial applications of butt welding are the jointing of steel in one form or another. In motor-car manufacture it is an invaluable process for the jointing of rear-axle casings and generally where large and small sections of steel need to be joined, before or after machining operations have been performed. It is a process which enables very high production rates to be achieved, coupled with economical use of material.

Many types of woodworking tools are made with a short piece of tool steel

TABLE VI.—FLASH WELDING MILD STEEL

Cross-sectional Area in Sq. In.	*kVA required*	*Mechanical Pressure in Lb.*	*Units per 1,000 Welds (approx.)*
$\frac{1}{2}$	25	800	7·0
$\frac{3}{4}$	30	1,750	20·0
1	60	3,150	34·0
$1\frac{1}{2}$	125	7,000	80·0
2	250	12,500	140·0
$2\frac{1}{2}$	300	25,000	200·0
3	350	35,000	350·0
4	500	60,000	550·0
$\frac{1}{16} \times 1\frac{1}{2}$	10	360	1·0
$\frac{1}{16} \times 4$	18	1,200	3·0
$\frac{1}{16} \times 20$	150	6,000	55·0
$\frac{1}{16} \times 120$	850	53,000	300·0
$\frac{1}{8} \times 3$	30	1,500	2·5
$\frac{1}{4} \times 4$	75	5,000	45·0
$\frac{1}{2} \times 4$	150	9,000	70·0

butt welded to a low-carbon steel shank. Plane irons and chisels are made in this way.

Chains, tubes, and railway lines are also flash-butt welded by larger types of machines.

Special-purpose machines are available for the welding of familiar objects like cycle rims and motor wheels which are produced in large numbers. Fig. 22 shows a 50-kVA fully automatic flash-butt welder which has been specially developed for the high-speed production of steel cycle rims. The machine is motor-operated, the motor being used to drive both the clamping heads and the flashing and upsetting cam. The machine is designed to run continuously, and is fitted with a signal light which indicates the correct moment for placing the next rim into position for welding. An output of 600 rims per hour is possible with this machine, but the speed can be varied to suit the speed at which the operator is able to work. This machine can also be used for other types of rims within its welding capacity. Pram wheel rims are an example.

OXY-ACETYLENE WELDING TECHNIQUE

FIG. 1.—OXY-ACETYLENE WELDING IN THE REPAIR SHOP
The operator is welding broken side frame of loom. (*The British Oxygen Co., Ltd.*)

OXY-ACETYLENE welding is the general name given to a process of joining two similar metallic substances by the application of heat derived from the rapid combustion of acetylene gas mixed with oxygen.

The two main methods employed are fusion welding and bronze welding.

In fusion welding the base metals are brought to their melting-point before welding commences, while in bronze welding the edges of the metals to be joined are heated to a temperature below their melting-point, and a bronze alloy is simultaneously melted and caused to flow over these edges and unite with them.

This article deals with the fusion-welding process, with special reference to the welding of mild steel.

Further articles cover the fusion welding of aluminium, cast iron, stainless steel, copper, etc., and the bronze-welding process.

In oxy-acetylene fusion welding it is usual to add the filler metal in the form of a welding rod when making a welded joint, although when working in thin

metals it may be found that no welding rod is required, but the joints are formed by merely fusing together the parts to be joined.

While no flux is required for mild steel, it is necessary in the welding of most other metals as a means of floating out the oxides and other impurities, and also to ensure a satisfactory bond.

The great advantage of the oxy-acetylene process is its flexibility. The welding plant can be easily taken to the job, the flame being adjustable, the regulation of the heat is easily controlled, and welding can be carried out in any desired position, vertical or overhead.

FIG. 2.—PORTABLE OXY-ACETYLENE LOW-PRESSURE EQUIPMENT

Showing sight-feed generator, oxygen cylinder, oxygen regulator, and blowpipe. (*Weldcraft, Ltd.*)

Equipment

There are two main systems of oxy-acetylene welding in general use, viz. "low pressure" and "high pressure," and they take their names from the manner in which the acetylene is supplied to the blowpipe. In either case, oxygen compressed into high-pressure cylinders is employed.

THE LOW-PRESSURE SYSTEM

Acetylene is produced in a generator by adding water to calcium carbide, or calcium carbide to water. The rate of generation may be controlled automatically, and the gas stored in the generator or in a separate holder.

Sight-feed Generator

Fig. 3 illustrates a carbide-to-water generator in which the pressure can be adjusted from 2 lb. to 15 lb. (9 lb. per square inch is the maximum working pressure allowed without special permission from H.M. Inspector of Explosives). The generator is made up of three principal parts—the carbide hopper, consisting of a Pyrex glass cylinder, the tank, and the flash-back arrester.

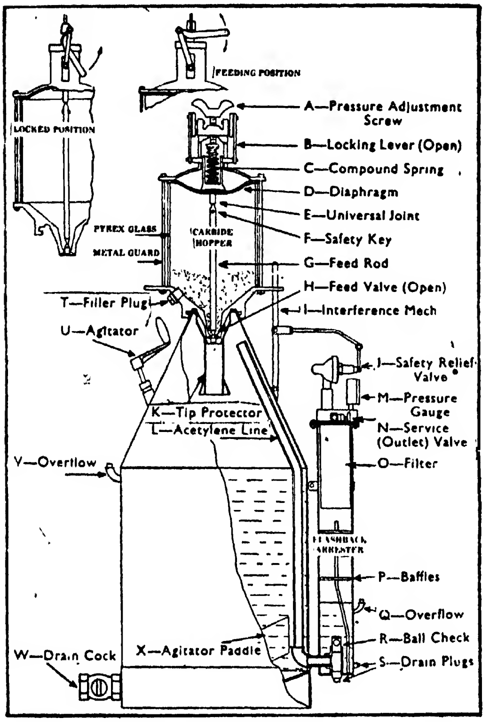


FIG. 3.—PORTABLE SIGHT-FEED ACETYLENE GENERATOR
(*Equipments, Ltd.*)

The pressure of the acetylene generated is regulated by the feeding mechanism. This consists of a regulating screw (*A*), by which the operator regulates the pressure of the spring (*C*) as desired, and is locked or released by the locking lever (*B*). This spring presses against the diaphragm (*D*), to which is attached a feed rod (*G*) by means of a universal joint (*E*).

When the locking lever is lifted, and the feed rod is allowed to drop so that the groove (*H*) allows the carbide to drop into the water in the tank, within a few seconds the operating pressure is obtained. The gas pressure against the diaphragm regulates the feed exactly and permits only sufficient carbide to drop into the water to replace the gas drawn off. If the outlet valve (*N*) is closed, the pressure will stop all flow of carbide and generation will cease.

The carbide passes through the patented tip protector (*K*) and is slaked in the water below. The acetylene passes out through the line (*L*), through the ball-check valve (*R*), is washed in the water in the flash-back arrester, passes baffles (*P*) through filter (*O*), through the condensation chamber above (where excess moisture is removed), and out through outlet (*N*).

This sight-feed generator is made so that the spring will not permit a downward pressure on the diaphragm of more than 15 lb., but should be adjusted to operate at 9 lb. Thus it is practically impossible to build up excessive pressures of acetylene. The safety key (*F*) is inserted into the feed rod so that, if the feed rod should become detached from the diaphragm, it could not drop into the tank and permit the carbide to be jumped into the water.

The safety relief valve (*J*) is set to open up if, for some reason, the gas

pressure should become excessive. This valve is so arranged with an interference mechanism (*I*) that it must be unseated every time the generator is recharged, thus ensuring that it will never become sludged, shut, and inoperative. The outlet valve (*N*) is fitted with a check, designed to prevent flash-backs from entering the flash-back arrester.

FIG. 4.—PORTABLE SIGHT-FEED ACETYLENE GENERATOR

Attaching hopper, after filling with carbide, to tank by means of breech-block fitting. Note oxygen cylinder. (*Equipments, Ltd.*)

Back-pressure Valves

Every generator must be equipped with a hydraulic back-pressure valve, the object of which is to prevent the oxygen from passing into the acetylene supply pipe or generator, where it would form an explosive mixture. The action of the hydraulic back-pressure valve is best understood by reference to Fig. 6. To put it into working order, with the gas inlet cock (*M*) closed

CARBIDE TO WATER ACETYLENE GENERATOR DATA
(*Sight-feed Medium Pressure Generators*)

Model	*Total Carbide Charge Lb.*	*Approximate Total Output Cub. ft./charge*	*Approximate Output Cub. ft./hr.*	*Working Pressure Lb./sq. in.*	*Type of Carbide*
12P	10½	52½	12	9	14 N/D or 1–2 M/M
25P	20	100	25	9	
50P	50	250	50	9	
100P	100	500	100	9	

(*Weldcraft, Ltd.*)

Fig. 5.—Closing interference mechanism of portable sight-feed generator

This acts as a safety device, as the hopper cannot be removed from the tank without first drawing back the mechanism, and so releasing any pressure that may remain in the generator prior to recharging. (*Equipments, Ltd.*)

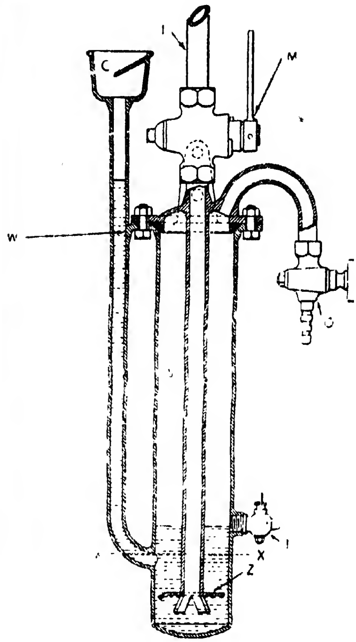


Fig. 6.—Back-pressure valve, inspection type

C, container *S*, main chamber
I, main central pipe *T*, water levelling cock
M, gas inlet cock *W*, filler pipe
O, gas outlet cock *Z*, baffle plate

(*C. S. Milne & Co., Ltd.*)

and the water-levelling cock (*T*) open, water is poured into the body until it reaches the level of (*T*), which is then closed. The gas inlet and outlet cocks (*M*) and (*Q*) are then opened and the valve is in operation. The acetylene is admitted through the main central pipe (*I*) and passes up through the water from the bottom of the main chamber of the valve (*S*), whence it is discharged through the gas outlet cock (*O*) to the work.

Should a back pressure be set up for any reason, the water level in (*S*) is depressed, the water being forced up through the pipe (*W*) into the filling cup (*C*). When the level of the water in the main chamber has been depressed to the port of the pipe (*W*), that is to say, to the level *XX*, the gases escape by way of the pipe (*W*) into the atmosphere. Also, should a back-fire occur, the products of the combustion will be discharged into the air and thus be prevented from

striking home into the generator. Also, a baffle plate (Z) prevents the water from the container being forced up the inlet pipe.

A hydraulic back-pressure valve is required for each operator. The reason for having a valve at each blowpipe, and not just one main valve on the pipeline, is to prevent a back-fire striking from the blowpipe of one operator to those of the others working on the same supply line.

HIGH-PRESSURE SYSTEM

High-pressure welding plants are very popular, the acetylene being stored under pressure in a cylinder in a similar manner to the oxygen cylinder. These plants are very easy of adjustment and convenient for their portability, as the whole plant can be arranged on a trolley and taken wherever the work is required.

Regulators or Reduction Valves

A regulator must always be used with acetylene and oxygen cylinders to reduce the high pressure in the cylinders to the considerably lower pressure required for the operation of the blowpipe. In general practice two-stage regulators are employed. Fig. 9 shows a single-stage regulator, which is more suitable for explanatory purposes.

The regulator is screwed into the cylinder by the flynut and the cylinder valve is opened, slowly admitting the gas into the lower tube of the regulator, where the high-pressure gauge (F) records the pressure of the

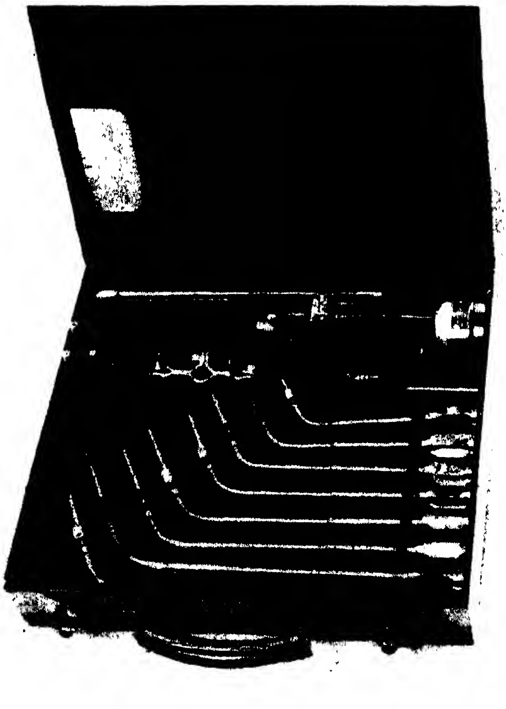


FIG. 7.—COMPLETE OXY-ACETYLENE WELDING AND CUTTING OUTFIT SUITABLE FOR USE ON LOW- OR HIGH-PRESSURE ACETYLENE SUPPLY

(*The British Oxygen Co., Ltd.*)

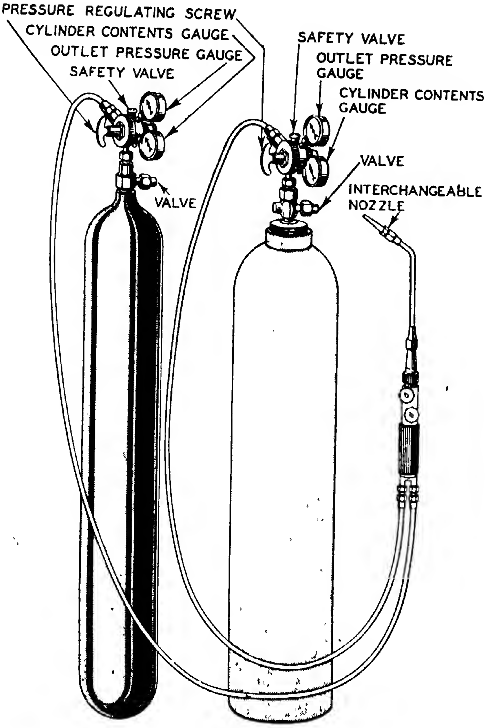


FIG. 8.—ASSEMBLY OF HIGH-PRESSURE EQUIPMENT

oxygen in the cylinder. Some of the gas then escapes through the control valve (*B*), which is arranged with a special valve seating so that the passage of the gas can be checked. Having passed through the nozzle into the body of the regulator, the gas passes through the upper tube and, if the outlet valve (*D*) is open, out through the supply pipe (*A*) to the work; *G* is the flynut and gland screw.

The pressure of the gas in the body of the regulator is exerted on a diaphragm (*E*) which is connected with the control (*B*). Another gauge (*L*) registers the pressure on the low-pressure side. When the pressure on this side tends to become higher than the actual pressure for which the regulator is set, the force on the diaphragm (*E*) tends to close the control (*B*), and thus the supply of gas is temporarily interrupted.

To adjust the instrument so that a required pressure may be obtained at the supply pipe (*A*), the pressure is set on a spring by means of the wingnut (*H*), this spring exerting a force on the opposite side of the diaphragm to that on which the gas acts. It must, in consequence, be compressed until its force balances the desired gas pressure on the diaphragm. By adjustment of the compression of this spring, any pressure on the outlet side may be obtained. A safety valve (*C*) is also fitted, which prevents dangerous pressures being set up in the body of the regulator in the event of leakage at the nozzle valve.

Blowpipes

It is recommended that a blowpipe of a reliable make should be used, and the principle of its action is shown diagrammatically in Fig. 10; it will be

observed that the high-pressure blowpipe is constructed on a different principle from the low-pressure type, and Figs. 11 and 12 show the details of their construction.

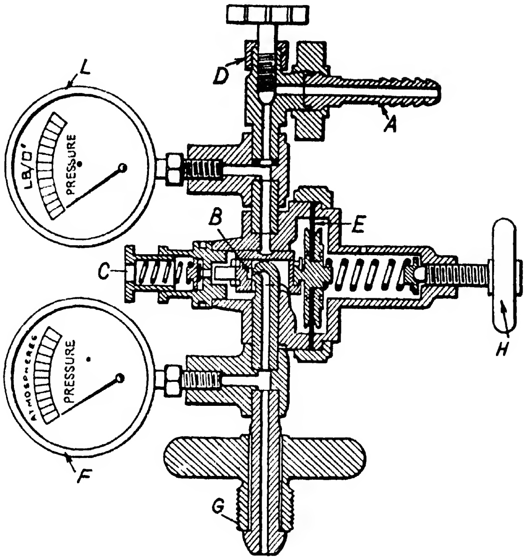


FIG. 9. -TYPICAL OXYGEN REGULATOR

A, supply pipe; *B*, small discharge nozzle; *C*, safety valve; *D*, outlet valve; *E*, diaphragm; *F*, high-pressure gauge; *G*, flynut and gland screw; *H*, wingnut; *L*, low-pressure gauge. (*The British Oxygen Co., Ltd.*)

Gases

A very high temperature is produced by the combustion of a fuel gas in an atmosphere of oxygen, and this makes possible the welding process by oxy-acetylene.

Many fuel gases, however, have been utilised at various times, but, of course, the chief one is acetylene. The proportion of acetylene and oxygen can be so arranged that three types of flames are produced at will, viz. neutral, oxidising, or carburising (Fig. 13).

REGULATOR DATA

Model	*Gas*	*Purpose*	*Calibration of Cyl. Contents Gauge*	*Calibration of Delivery Gauge Lb./sq. in.*	*Maximum Delivery Pressure Lb./sq. in.*
O.R. 12 (two-stage pressure reduction type) .	Oxygen	Welding	0–225 ats.	0–60	30
A.R. 9 (two-stage pressure reduction type	Acetylene	Welding or cutting	0–600 lb./sq. in.	0–60	30
O.R. 13	Oxygen	Heavy welding or cutting	0–225 ats.	0–250	150

(*The British Oxygen Co., Ltd.*)

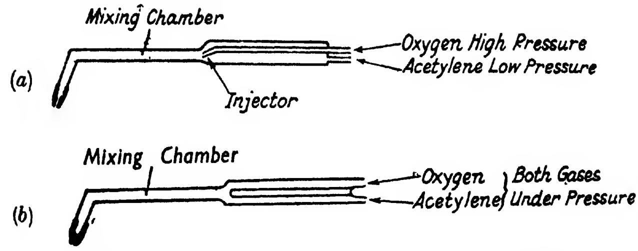


FIG. 10.—DIAGRAMMATIC SECTIONS THROUGH HIGH- AND LOW-PRESSURE BLOWPIPES
(*a*) Low pressure. (*b*) High pressure.

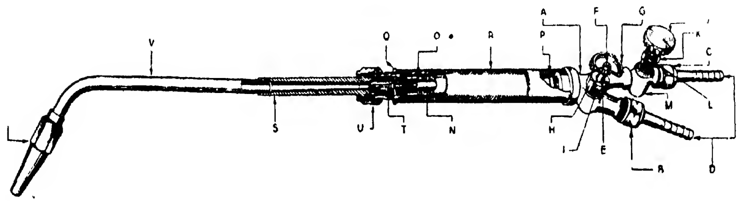


FIG. 11.—LOW-PRESSURE BLOWPIPE

A, back end; *B*, acetylene union nut (left-handed); *C*, oxygen union nut (right-handed); *D*, flexible tube nozzle; *E*, acetylene control-valve spindle; *F*, acetylene control-valve nut; *G*, acetylene control-valve recessed head; *H*, acetylene control-valve gland nut; *I*, acetylene control-valve gland-nut washer; *J*, oxygen control-valve spindle with head; *K*, oxygen control-valve gland nut; *L*, oxygen control-valve gland-nut washer; *M*, oxygen control-valve body; *N*, oxygen tube; *O*, acetylene tube with head; *P*, acetylene tube with locknut; *Q*, handle tube nut; *R*, milled handle tube; *S*, mixing chamber; *T*, injector; *U*, head nut; *V*, head tube; *W*, copper nozzle.

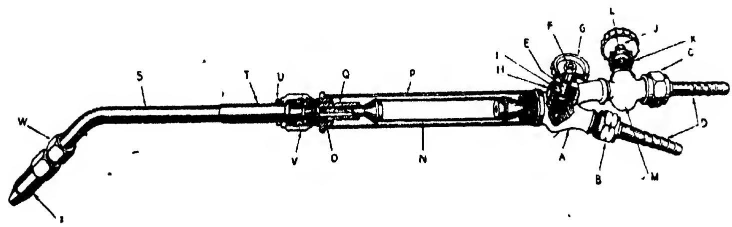


FIG. 12.—HIGH-PRESSURE BLOWPIPE

A, back end; *B*, acetylene union nut (left-handed); *C*, oxygen union nut (right-handed); *D*, two flexible-tune nozzles; *E*, acetylene control-valve spindle; *F*, acetylene control-valve spindle nut; *G*, acetylene control-valve reeded and recessed head; *H*, acetylene control-valve gland nut; *I*, acetylene control-valve gland-nut washer; *J*, oxygen control-valve spindle with head; *K*, oxygen control-valve gland nut; *L*, oxygen control-valve gland-nut washer; *M*, oxygen control-valve body; *N*, tapered oxygen connecting piece; *O*, oxygen nipple; *P*, milled handle tube; *Q*, head piece; *S*, short head tube; *T*, mixing chamber; *U*, nut collar for mixing chamber; *V*, hexagon nut for head; *W*, nozzle nipple for copper nozzle; *X*, copper nozzle.

The neutral flame is obtained when equal quantities of oxygen and acetylene are burning, and is indicated by two distinct zones—the central white cone and an outer envelope. A neutral flame is required for welding mild steel.

The oxidising flame (excess oxygen) is short and pale. The central cone is short, with a violet tinge.

The carburising flame (excess acetylene) is indicated by a ragged bluish-white feather surrounding the central white cone.

The temperature at the cone tip of an oxy-acetylene flame is about 3,100° C.

Hydrogen in the presence of oxygen gives 2,400° C.

Methane under similar conditions gives 1,800° C.

Coal-gas with oxygen gives a temperature of about 2,000° C. and can be used for bronze welding.

Oxygen Cylinders

Oxygen cylinders are always painted black, and have right-hand thread connections. They should be taken great care of and not stored in a position of great heat. The gas is compressed to 132 atmospheres at 60° F. or 1,980 lb. per square inch.

To calculate the quantity of oxygen taken from an oxygen cylinder, note the pressure reading before and after use. Then:

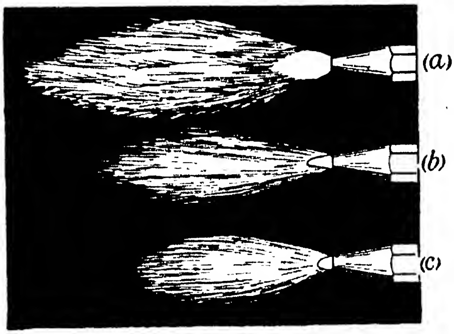


FIG. 13.—THREE TYPES OF FLAMES
(*a*) Carburising flame. (*b*) Neutral flame. (*c*) Oxidising flame.

Multiply the drop in atmospheres pressure—

by $\frac{5}{6}$ for a 100-cub.-ft. cylinder;
by $\frac{5}{4}$ for a 150-cub.-ft. cylinder; or
by $\frac{5}{3}$ for a 200-cub.-ft. cylinder.

Example:

Pressure before use . .	103 atmospheres
Pressure after use . .	34 atmospheres
Pressure drop . .	69

A 100-cub.-ft. cylinder was used, therefore gas consumed $= 69 \times \frac{5}{6} =$ 58 cub. ft.

Acetylene Cylinders

Acetylene cylinders are always painted maroon, and are made with a flat bottom, and the thread connections are left-hand.

The gas is compressed to 225 lb. per square inch at 60° F. (This reading for a full cylinder may vary according to prevailing temperature. Cold reduces pressure, heat or storage in warm places increases pressure. Contents will remain the same.)

When using dissolved acetylene, the maximum discharge rate for each cylinder should be not more than 20 per cent. of its capacity in cubic feet per hour. This would mean, of course, that for a 200-ft. cylinder the rate of gas consumption should be not more than 40 cub. ft. of acetylene per hour.

To calculate the quantity of acetylene taken from a dissolved acetylene cylinder:

Weigh before and after use, find the loss in weight in ounces, and divide by 1·1. This gives the number of cubic feet of gas consumed. (Pressure-gauge readings are not an accurate guide to the contents of a D.A. cylinder.)

Example:

	lb.	oz.
Weight of cylinder before use . .	194	7
Weight of cylinder after use . .	189	2
Weight of gas used	5	5

Volume — 85 ÷ 1·1 = 77 cub. ft.

DOWNHAND BUTT WELDING

There are two methods of downhand welding by the oxy-acetylene flame, which are known as "leftward" and "rightward" welding.

Leftward Welding

The leftward method of welding is the oldest and widest established method for the butt welding of steel plate. Recent developments have shown that above certain thicknesses the leftward method may be economically replaced by the rightward method of welding; but within its sphere of application, which is really only limited by thicknesses, it gives excellent results, and is the most satisfactory method both from the point of view of the economy of the joint and the resultant mechanical properties of the weld.

In making a leftward weld, the operator starts with his blowpipe at the right-hand edge of the seam, and the filler rod precedes the blowpipe, as shown in Fig. 14. The blowpipe is given a forward motion, with a slight sideways movement just sufficient to maintain both edges melting at the desired rate, and the welding rod is moved progressively along the weld seam.

It is unnecessary to bevel plate up to $\frac{1}{8}$ in. in thickness, but there should be an included angle of bevel of at least 80° for thicknesses of $\frac{1}{8}$–$\frac{3}{16}$ in. Above $\frac{3}{16}$ in. thick, under normal conditions, it is not economical to use the leftward method, but as stated previously, it should be replaced by the rightward method.

Rightward Welding

By the rightward method the operator begins, from his point of view, at the left of the seam and proceeds towards the right, as illustrated in Fig. 15. The

LOW-PRESSURE BLOWPIPE DATA FOR DOWNHAND BUTT WELDING MILD STEEL

Plate Thickness *In*	*Nozzle Size*	*Oxygen and Acetylene Gas Consumption Cub. ft./hr.*	*Oxygen Regulator Pressure Lb./sq. in.*		*Approximate Speed of Welding Ft./hr.*	
			Model LC	*Model LD*	*Model LC*	*Model LD*
$\frac{1}{32}$	1	1	7	7	30	30
$\frac{3}{64}$	2	2	7	7	30	30
$\frac{1}{16}$	3	3	10	10	25–30	25–30
$\frac{3}{32}$	5	5	12	12	20–25	20–25
$\frac{1}{8}$	7	7	14	14	18–20	18–20
$\frac{5}{32}$	10	10	16	16	15–18	15–18
$\frac{3}{16}$	13	13	18	18	12–15	12–15
$\frac{1}{4}$	18	18	18	18	10–12	10–12
$\frac{5}{16}$	25	25	20	20	7–8	7–8*
$\frac{3}{8}$	35	35	22	—	6–7	—
$\frac{1}{2}$	45	45	24	—	4½–5	—
$\frac{3}{4}$	55	55	26	—	3–3¼	—
1	70	70	28	—	2–2½	—
Over 1	90	90	30	—	Depending on thickness	—

* $\frac{5}{16}$-in. thickness is limit for welding mild steel with model LD blowpipe.

(*The British Oxygen Co., Ltd.*)

HIGH-PRESSURE BLOWPIPE DATA FOR DOWNHAND BUTT WELDING MILD STEEL

Plate Thickness *In.*	*Nozzle Size*	*Oxygen and Acetylene Gas Consumption Cub. ft. hr*	*Oxygen and Acetylene Regulator Pressures Lb./sq. in.*		*Approximate Speed of Welding Ft./hr.*	
			Model CH	*Model DH*	*Model CH*	*Model DH*
$\frac{1}{32}$	1	1	2	2	30	30
$\frac{3}{64}$	2	2	2	2	30	30
$\frac{1}{16}$	3	3	2	2	25–30	25–30
$\frac{3}{32}$	5	5	2	2	20–25	20–25
$\frac{1}{8}$	7	7	2	2	18–20	18–20
$\frac{5}{32}$	10	10	3	3	15–18	15–18
$\frac{3}{16}$	13	13	3	4	12–15	12–15
$\frac{1}{4}$	18	18	3	7	10–12	10–12
$\frac{5}{16}$	25	25	4	9	7–8	7–8*
$\frac{3}{8}$	35	35	4	—	6–7	—
$\frac{1}{2}$	45	45	6	—	4½–5	—
$\frac{3}{4}$	55	55	8	—	3–3¼	—
1	70	70	10	—	2–2½	—
Over 1	90	90	14	—	Depending on thickness	—

$\frac{5}{16}$-in. thickness is limit for welding mild steel with model DH blowpipe.

(*The British Oxygen Co., Ltd.*)

blowpipe is not moved laterally across the V; its only movement is a steady axial one along the centre line of the seam as the weld is built up. The flame is directed down into the bottom of the V, where it maintains a small hole at the edges of the plate. This ensures that the operator is obtaining perfect welding penetration right down to the bottom of the V, and at the same time the formation of a neat, regular bead on the reverse side of the plate.

The filler rod follows the flame, and, being kept always parallel with the surface of the molten puddle, it is moved laterally backwards or forwards across the V from the molten edge of one plate to the other.

With rightward welding no bevel is necessary up to thicknesses of $\frac{5}{16}$ in., and a 60° bevel is sufficient above that thickness, whereas by other methods a 90° bevel is required. The effect of this on the speed of welding is obvious. Owing to the smaller amount of metal to be laid down in the case of rightward welding, and the better utilisation of the heat of the blowpipe flame, much greater speed may be attained, with corresponding economy in time and materials.

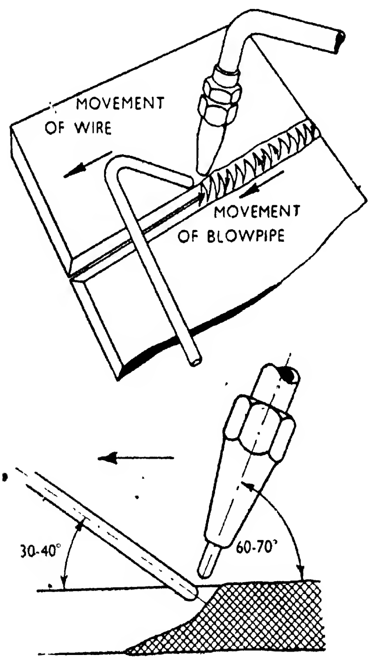


FIG. 14.—THE LEFTWARD METHOD OF WELDING

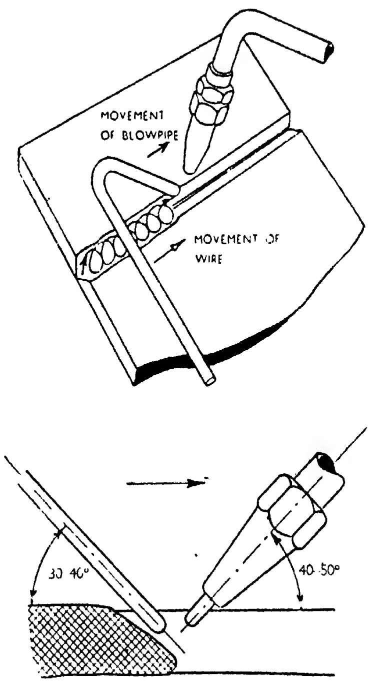


FIG. 15.—THE RIGHTWARD METHOD OF WELDING

(*The British Oxygen Co., Ltd.*)

Fig. 16 illustrates the edge preparation required for downhand butt welding of mild steel.

FILLET WELDING

Fillet welds are extensively used in structural work and engineering production for reinforcing and strengthening purposes.

Making Underhand Fillet Lap Joints

Hold the rod at an angle of 30–40° and the blowpipe 60–70° to the horizontal, but incline them slightly towards you.

First tack weld the two plates together by melting and depositing a small amount of metal from the welding rod.

In welding, employ the same movements of filler rod and blowpipe as already described for making butt welds by the leftward method.

Fig. 17 (*A*) shows a single fillet lap joint.

If properly executed, a double fillet lap joint (Fig. 17 (*B*)) is as strong as the original metal. A strap joint, using a fillet weld, can be used to strengthen a butt joint, as shown in Fig. 17 (*C*).

A corner joint (Fig. 17 (*E*)) may be used when two plates are to be welded at right angles, the weld metal being deposited in the outer corner. Build up the weld metal to exceed slightly the thickness of the original metal.

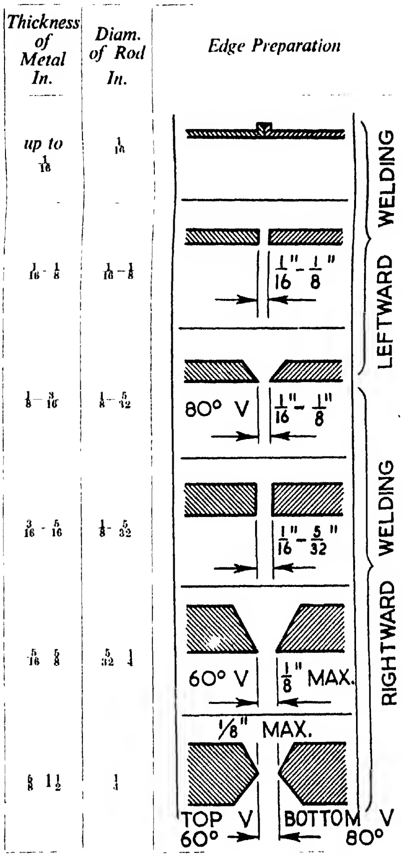


FIG. 16.—EDGE PREPARATION FOR DOWNHAND BUTT WELDS IN STEEL

A Possible Fault in Fillet Welding

In fillet welding, take particular care to see that the corner is sufficiently heated, otherwise imperfect fusion will occur along the corner, complete amalgamation of the metal only taking place along the two edges. Imperfect fusion at the corner will take place if the welding rod is allowed to shield the

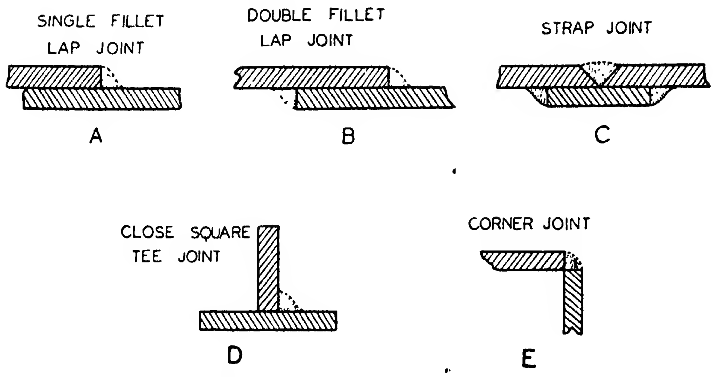


FIG. 17.—EXAMPLES OF FILLET WELDS

corner from the flame. Remember, therefore, to lower the welding rod into position when the edges are fusing, and direct the flame round the rod.

VERTICAL WELDING

The principal advantages of the vertical method of welding mild steel over any other method of oxy-acetylene fusion welding are considerably reduced gas consumptions, absence of edge preparation up to $\frac{5}{8}$ in. thickness, and uniform contraction of the weld, leaving the plate flat. Again, much smaller blowpipes are used for the upward vertical method, hence less heat is put into the plate, with consequent reduction in expansion and contraction, increased ease of control of the metal, and added comfort of the welder.

The single-operator technique (Fig. 18) is used for plates up to $\frac{3}{16}$ in., while the two-operator method is used for plates from $\frac{3}{16}$ in. to $\frac{5}{8}$ in. (Fig. 19).

Welding Method

At a short distance from the bottom of the plate a hole is pierced with the blowpipe and the fused metal runs together beneath the hole. The rod is applied to the molten crater and runs round the sides of the hole. The blowpipe is given a semi-circular movement from side to side at the bottom of the hole, and the rod executes a corresponding movement at the top of the hole. The blowpipe is moved upwards, the rod preceding it at the same rate. In this manner a narrow bead of metal is laid down, and heating of the base metal is limited to an extremely small area on either side of the weld.

In the case of the single-operator technique, the blowpipe is held more steeply to the plate as the thickness increases.

For $\frac{1}{16}$-in. plate the blowpipe is held very flat indeed, otherwise excessive fusion of the metal will result and the weld will get completely out of control.

In the case of $\frac{3}{16}$-in. plate, however, it is necessary to direct the whole of the

heat on to the point being welded in order that fusion may take place with sufficient speed.

In the case of the two-operator technique, there is no variation of the angle of the blowpipe. The blowpipes must be inclined at the same angles on each side of the plate, and the speed of advance must be identical in the case of each welder. The success of the method depends on complete harmony between the two welders.

Allowing for Expansion and Contraction

When welding two sheets together, the heat of the metal surrounding the weld tends to increase as the welding proceeds, so that you get a corresponding increase in expansion in the direction of the weld and a tendency to contract as the welded metal cools.

One method of counteracting the effects of expansion and contraction when welding thin plate consists in tack welding. Tack welds are welds about 1 in. in length, or less, made at regular intervals along the line of weld.

Buckling during tacking on very thin plate may be avoided by holding the plates in position by pressure. Otherwise buckling may be removed with a mallet.

Another method of countering the effects of expansion and contraction, used with thick plate, is to set the two plates purposely out of line, so that the forces of expansion and contraction will finally pull them into line.

There are certain recognised amounts of divergence, and these allowances depend upon the metal being welded. The allowances, of course, also depend upon the thickness of the material and on the speed of welding.

If for any reason it is necessary that the parts to be welded be absolutely parallel, instead of placed at an acute angle as explained above, welding should

VERTICAL WELDING DATA FOR MILD STEEL

Plate Thickness *In.*	*Nozzle Size*	*Oxygen and Acetylene Gas Consumption* *Cub. ft./hr.*	*Oxygen Regulator Pressure* *Lb./sq. in.*	*Diameter of Welding Rod*	*Welding Speed* *Ft./hr.*	*No. of Operators*
$\frac{1}{16}$	2	2	2	$\frac{1}{16}$	15	1
$\frac{3}{32}$	3	3	2	$\frac{1}{16}$	12	1
$\frac{1}{8}$	5	5	2	$\frac{5}{64}$	10	1
$\frac{5}{32}$	7	7	2	$\frac{5}{64}$	8	1
$\frac{3}{16}$	10	10	3	$\frac{3}{32}$	7	1
$\frac{3}{16}$	3	3	2	$\frac{1}{16}$	12	2
$\frac{1}{4}$	5	5	2	$\frac{3}{32}$	10	2
$\frac{5}{16}$	5	5	2	$\frac{1}{8}$	$8\frac{1}{2}$	2
$\frac{3}{8}$	7	7	2	$\frac{5}{32}$	$7\frac{1}{2}$	2
$\frac{1}{2}$	10	10	3	$\frac{5}{32}$	$6\frac{1}{4}$	2
$\frac{5}{8}$	18	18	4	$\frac{3}{16}$	6	2

(*The British Oxygen Co., Ltd.*)

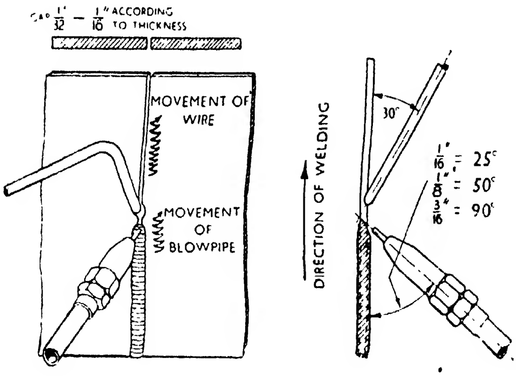


FIG. 18.—VERTICAL WELDING—SINGLE OPERATOR

For plates up to $\frac{3}{16}$ in. thickness. (*The British Oxygen Co., Ltd.*)

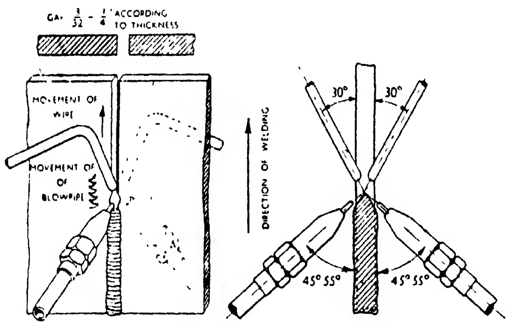


FIG. 19.—VERTICAL WELDING—TWO OPERATORS

For plates $\frac{3}{16}$–$\frac{5}{8}$ in. thickness. (*The British Oxygen Co., Ltd.*)

begin about half-way between the two extremities of the weld, and then should recommence in the reverse direction for a short distance; then again, welding should be carried on in the opposite direction, and so on to completion.

General Conditions

All welding work should be thoroughly cleaned before attempting to make a weld. Grease, paint, and dirt must be mechanically removed before commencing the welding operation.

Eye Protection

It is important that the welder should be provided with a pair of goggles which will almost completely protect the eyes. The frames should be of heat-resisting and fireproof materials and correctly shaped to fit snugly to the face, and with particular notice to the nose bridge, so as to obtain the correct distance between the two frames. Of amber glass, smoke-tinted to a density suiting the vision of the operator, the lenses should be ground and polished and provided with clear glass covers which can be renewed when required. (See also page 8 of this volume.)

Oxy-acetylene Welding in Workshop Practice

The application of oxy-acetylene welding technique to cast iron, stainless steels, and non-ferrous metals is described in detail in the next section.

OXY-ACETYLENE WELDING

(FERROUS AND NON-FERROUS)

THE preceding article has dealt with the technique of oxy-acetylene fusion welding with special reference to the welding of mild steel.

While the same type of equipment and the general principles apply to the remainder of the weldable metals, there are differences in the welding operations.

This article deals with these differences for the welding of cast iron, stainless steels, aluminium, copper, magnesium, brasses, and zinc-bearing bronzes.

STAINLESS STEELS

All the varieties of the two main classes of stainless steels, namely, air-hardening (martensitic) and non-air-hardening (austenitic), can be oxy-acetylene welded.

Martensitic stainless steels need to be reheated after welding, as they tend to harden when cooled in air after the welding temperature, and become brittle in material adjacent to the weld, with a consequent risk of cracking.

The ordinary types of austenitic stainless steels also need to be reheated after welding to restore their resistance to corrosion and to prevent weld decay. Most manufacturers, however, produce austenitic stainless steels of special welding qualities, which do not require heat treatment after welding. It is therefore desirable to use the special welding qualities and suitable welding rods whenever possible.

Welding Rods

Use a welding rod of similar composition to that of the material being welded. It is better to use a properly prepared welding rod rather than strips cut from the sheet. This is because of losses of certain elements during welding which are allowed for in the specially made rods. Another drawback is that strips cut from the sheet do not contain modifying elements such as columbium, titanium, or molybdenum, and that they also oxidise more rapidly than drawn wire and therefore do not give such a satisfactory result.

The size of wire should be the same as the thickness of the sheet to be welded.

Flux

The use of a suitable flux is essential for all types of stainless steels, as it assists in securing good penetration by protecting the underside against oxidation by atmospheric contamination.

The best method of applying flux is to paint it in the form of a paste on the underside of the edges to be welded. Apply sparingly. Another method of applying the flux is to dip the end of the heated rod into it and then to heat the rod so that it will be varnished with the flux.

Preparation

Prepare the edges of the metal in the same way as for mild steel. The expansion will be found to be greater than for mild steel, the amount varying with the type; 50 per cent. greater expansion is usual, although it may be considerably greater with some types. Allowance should therefore be made for this expansion when setting up the work. Tacking when employed will have to be stronger than for mild steel.

Before welding, carefully clean and descale the surface to be welded.

Welding Flame and Nozzle Size

It is important to use a neutral flame or one that has a slight excess of acetylene at the end of the white cone, not more than about half the length of the cone. This will ensure that the flame is not oxidising, which gives a porous weld. A slight haze of acetylene at the start will overcome the difficulty often experienced in maintaining a strictly neutral flame during welding owing to the fact that as the blowpipe gets hot, the acetylene supply tends to diminish. Too much acetylene will produce a hard and brittle weld with unsatisfactory corrosion resistance.

The same size of nozzle as for welding mild steel of similar thickness is usual.

Manipulation of the Blowpipe and Rod

When welding, keep the molten puddle as quiet as possible and progress at a uniform speed. Keep the puddle covered by the flame all the time to protect the molten metal from contact with the air. The white cone should be kept as near as possible to the surface of the metal without touching. The end of the welding rod should be kept in the pool of metal. As most stainless steels heat up more rapidly than mild steel, a slight side to side movement is imparted to the blowpipe. This will also assist penetration.

After-treatment

With the special non-hardening steels of welding quality, no heat treatment is necessary after welding, but it is necessary to remove the scale by grinding or polishing, or by means of a descaling solution.

Information should be obtained from the manufacturers of the stainless steels it is proposed to weld as to their recommendations for after-treatment of their steels—annealing or softening and descaling.

CAST IRON

Before describing the procedure for welding grey cast iron, a brief outline is given on the production of the three general types, namely, Grey Cast, White Cast, and Malleable Cast Iron.

White Cast Iron

Of these three types, the welding of white cast iron should be avoided. As the name implies, this iron shows a white fracture when broken. It is produced when molten iron containing about 3 per cent. of carbon in solution is cooled down very rapidly, and the effect of such rapid cooling is to render impossible the decomposition of cementite into graphite and ferrite. The resultant structure consists of masses of cementite—a hard iron-carbon compound in a background of pearlite. So much combined carbon renders the casing very hard, brittle, and difficult to machine.

Grey Cast Iron

Grey cast iron may be recognised by the colour of the metal when fractured. As distinct from white cast iron, grey cast iron is produced when molten iron having a carbon content of 3 per cent. is allowed to cool down *slowly*. Much of the carbon exists as a compound (cementite, Fe_3C) of the iron when molten, and this compound is dissolved in the iron. Upon the cooling of the iron the cementite breaks down into its constituents, iron and carbon, and the carbon is thrown out of solution in the form of long black flakes. The metal owes its colour to the presence of these flakes of graphite.

Some of the carbon is not thrown out of solution, however, but is retained in combination with the iron as cementite; and when the iron finally cools down to room temperature the cementite is deposited in very thin layers side by side with the pure iron (ferrite). Pearlite—the name given to this particular combination of cementite and ferrite—is a very important constituent, occurring also in the majority of industrial steels, and owing its usefulness to the combination of the strength and hardness of cementite with the machinability and tenacity of ferrite. Grey cast iron has excellent mechanical properties and besides welding may be machined

Malleable Cast Iron

Malleable cast iron is of two general kinds: Whiteheart Malleable and Blackheart Malleable.

Combining some of the properties of steel with some of the properties of cast iron, malleable cast iron is manufactured by heating for some days special grades of white cast iron of a high silicon and fairly low carbon content to about 800°–900° C. in the presence of materials such as iron ore, mill-scale, sand, etc., in an annealing pot. Breakdown of the cementite into minute and evenly distributed particles of soft graphitic ("temper") carbon ensues. The hardness and brittleness of the original white iron is thus destroyed, its strength maintained, and a ductility and malleability not normally associated with cast iron conferred upon it.

By causing some of the carbon to migrate towards the outer layer of the casting, this process also effects a subsequent oxidation—a decarburising action which results in the formation of a layer of iron of low carbon content round the casting; in other words, steel is formed round the outer layer of the casting, while the casting has all the malleability of steel without the low resistance to shock of cast iron.

When the malleabilising process depends chiefly upon the decarburisation of the casting, whiteheart malleable iron is formed. Decarburisation of the casting is not in general a good thing. When the process depends chiefly upon decomposition of the cementite, the casting is known as blackheart, and the process entails the coalescence of some of the deposited carbon into clumps or nodules.

Bearing in mind the conditions imposed upon its production, the welder will appreciate that no deposition can be made with cast iron having the structure of malleable cast iron. In most cases bronze welding is the most satisfactory method of repairing malleable castings.

Additional Constituents of Cast Iron

Phosphorus reduces the melting-point and increases the fluidity of cast iron. In cast irons for ordinary engineering use, as distinct from those used for ornamentation, the phosphorus content seldom exceeds 0·5 per cent. As iron phosphide it forms a compound with the iron and melts at about 950° C. Phosphorus is usually introduced in the melt when sharp castings are required. When present in excess of 1 per cent., phosphorus militates against the mechanical properties of the cast iron inasmuch as the iron tends to become brittle.

Most cast irons in general use have about 1·5–2 per cent. of silicon, though the occurrence of this element may vary in amount from 0·5 to 3 per cent. By breaking down the cementite and so depositing graphite, silicon effects a softening of the iron, a slight reduction in tensile strength, and an increase in machinability; silicon helps, therefore, to produce grey irons.

In connection with sulphur, it should be noted that a small amount hardens the iron and improves its wearing qualities, whilst a large amount is distinctly harmful. The sulphur content in cast iron should therefore not exceed 0·1 per cent. A desirable percentage of sulphur in cast iron tends to prevent the formation of graphite, and is usually added to improve the "chilling" effect of metal moulds. In the latter process the outer layer of the casting is made to cool quickly; thus, while maintaining an ordinary grey iron core, a hard-wearing and graphite-free surface is imparted.

Manganese occurring in cast iron in quantities from 0·1 to 2 per cent. renders the cementite more stable, causing a harder and stronger casting. It combines with the sulphur in the iron, and so prevents the formation of the iron-sulphur compound to which is attributed excessive brittleness in cast iron.

Preparation for Welding Cast Iron

There are two distinct phases of preparing a casting for welding:

(*a*) The cleaning, chamfering, and setting up of the part to be welded, and

(*b*) the preheating of the casting.

The location of the casting for the welding operation must be considered with reference to the ease of access to the parts to be welded, the character and location of the welding equipment, and the possible damage to parts and attachments to the casting during and after the welding.

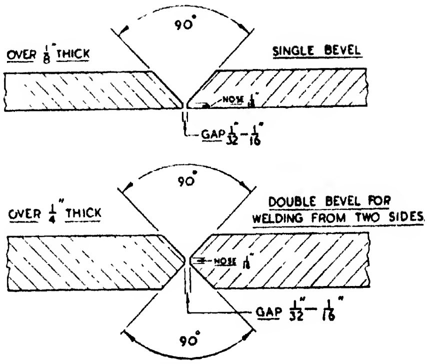


FIG. 1.—EDGE PREPARATION FOR CAST-IRON WELDING
(*The British Oxygen Co., Ltd.*)

Edge Preparation

No bevel is required for castings up to $\frac{1}{8}$ in. thickness. Between $\frac{1}{8}$ in. and about $\frac{3}{8}$ in., they should be bevelled on one side only to an included angle of 90°, while for greater thickness they should be bevelled from both sides. Fig. 1 illustrates the edge preparation for cast-iron welding.

In the case of production work, this can be done mechanically, and in the case of repair work, it may be done by a hammer and chisel, or by grinding.

Preheating

This is essential to the successful welding of cast iron, for two reasons. Firstly, it is the only satisfactory method of preventing stresses being set up in the casting, either during or after welding, which are liable to cause fracture or distortion. Secondly, it ensures that the weld will cool down slowly, and enable a machinable and strong deposit to be made, instead of the hard brittle, unmachinable deposit of white iron which would result from rapid cooling.

In practice it is usually best to preheat the whole of the casting, and this should be done by the most economical means available. For small jobs, where the part to be welded is free to expand and contract, the oxy-acetylene blowpipe itself may be used to preheat the surface. In the majority of cases, however, it is best to have a gas-fired preheating furnace, or to construct a temporary charcoal furnace. Coke should not be used, because too high a local temperature usually results from its combustion. Fig. 2 shows the method of building a temporary charcoal furnace for a typical job.

The combustion of the charcoal fuel of the preheating furnace should not be speeded by the use of an air blast. If it is found that the heating is proceeding too rapidly, the draught into the furnace through the spaces between the staggered bricks at the bottom may be regulated by closing some of the spaces with firebricks or pieces of asbestos paper.

While the heating is going on, and during the welding after the casting has been preheated, protection against draughts must be ensured. The chilling action of a draught upon a preheated casting may not only prevent successful welding, but may also seriously injure the casting itself.

Preheating should be continued until the material has reached 600° C., i.e. dull red colour, in order that the best results may be obtained.

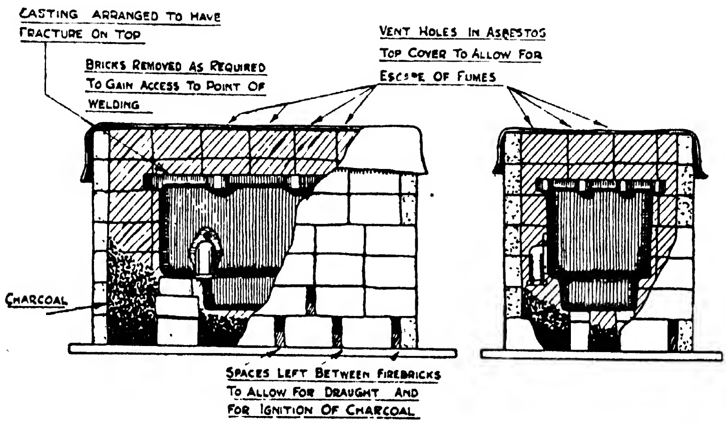


FIG. 2.—METHOD OF BUILDING A TEMPORARY CHARCOAL FURNACE FOR CAST-IRON WELDING (*The British Oxygen Co., Ltd.*)

Flux

Cast iron when raised to a red heat very rapidly oxidises. To ensure a satisfactory weld a welding flux must therefore be used.

A suitable cast-iron flux should consist of a balanced mixture of alkaline borates, carbonates, and bicarbonates, together with some special slag-producing compounds, the purpose of such a flux being to dissolve the oxide of iron and to protect the metal from oxidation whilst welding is in progress. To prevent attack by the surrounding atmosphere, the flux floats on the surface of the molten metal and forms a coating of protective slag.

Use the flux powder sparingly and carefully. By heating the end of the welding rod and dipping it in the tin of flux, the powder, spread over the surface of the welding rod, will melt in the blowpipe flame and run on to the surface of the metal to be welded.

Welding Rod

A cast-iron welding rod should not be too high in combined carbon. It should contain a fairly high proportion of silicon and be of a fairly low carbon content. Since some silicon is lost, in the form of slag, during the welding operation, an excess of silicon over that required in the finished weld is necessary.

FIG. 3.—REPAIR OF CAST-IRON CYLINDER BLOCK

The casting has been preheated in a gas-heated furnace. This type of preheating is used when the damage to the cylinder block is extensive or deep-seated. Note draught excluders to maintain heat during welding. (*Laystall & Co., Ltd.*)

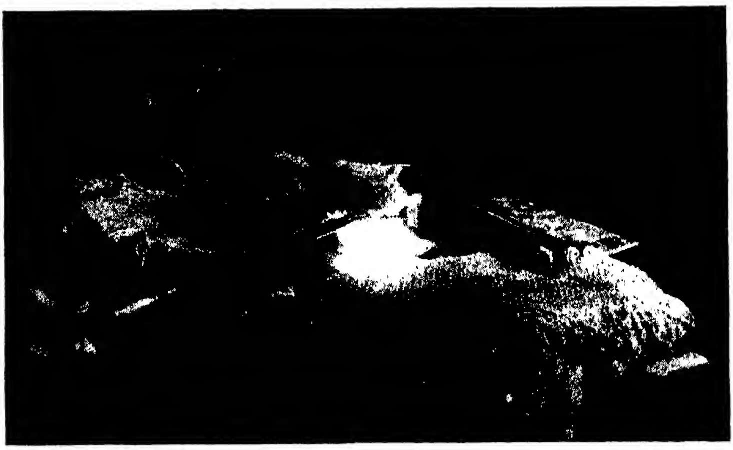


FIG. 4.—REPAIR OF CAST-IRON CYLINDER-BLOCK FACE

The casting has been preheated in a temporary furnace by preheating torches. Note only the actual portion welded is exposed, draught shields of asbestos cloth conserving the heat where possible. (*Laystall & Co., Ltd.*)

Silicon, in its character of deoxidiser, destroys the oxide of iron, and thus prevents blowholes and decarburisation of the metal.

Nozzle Size and Blowpipe Flame

In general, the same size of nozzle is used as for welding mild steel of similar thickness.

For cast-iron welding it is most important that a strictly neutral flame is used. If there is a slight excess of oxygen in the flame, the blowpipe flame will naturally tend to oxidise the metal, and will form either a weak weld containing burnt metal or a hard unmachinable deposit.

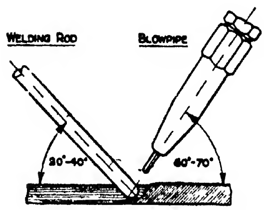


FIG. 5.—ANGLES OF ROD AND BLOWPIPE FOR CAST-IRON WELDING

Keep the white cone of the blowpipe flame about $\frac{1}{8}$–$\frac{3}{16}$ in. away from the molten metal, taking care that the correct-size nozzle is chosen for the metal thickness to be welded. Too large a nozzle size may have a tendency to overheat the metal.

Method of Welding

The leftward or forward method is adopted for the welding of cast iron. The angles of the rod and blowpipe are shown in Fig. 5.

Keep the blowpipe at quite a steep angle; cast iron when molten is very fluid, and the force of the flame will act as a check to keep the metal in place. Should this not be done, the molten metal will tend to flow on to the edges of the prepared V; as these edges have not yet been brought to welding heat, adhesion will follow.

Apply the welding rod to the pool and play the blowpipe around it. Melt the rod in the pool, taking care not to remove the end of the welding rod from the flame more than is necessary. Failure to follow this last instruction may result in excessive oxidation.

Finishing Off the Weld

In some cases the whole of the oxide and slag, together with any surplus weld metal, can be removed whilst the weld is in its plastic condition by rubbing an old flat file over the surface. This must be done before the weld has cooled down, as the scum sets to a scale sufficiently hard to cause great difficulty if removal is delayed.

Allow the weld to cool down slowly—if a preheating furnace has been used, allow the job to cool in the furnace; cooling down in a tub of ashes, cinders, or warm powdered lime is recommended where the job is small. Rapid cooling will affect the machinability of the weld, and may very possibly cause fracture, either adjacent to the weld or in some other part of the casting.

Never allow the completed weld to cool in, or near, draughts or air currents.

Never hammer cast-iron welds after completion.

COPPER

Besides hard soldering, soft soldering, brazing, bronze welding, riveting, and screwing, copper may also be fusion welded. There were, however, many difficulties in the way of the development of copper welding to its present satisfactory stage.

Most industrial copper contains a certain amount of oxygen, present in the metal as cuprous oxide.

Cuprous oxide occurs in the form of spheroidal particles distributed throughout the mass of the metal, and is not, by itself, harmful. When, however, the copper is heated to temperatures near melting-point, the cuprous oxide forms, with the copper, an eutectic which migrates to the grain boundaries under the effect of heat, and so tends to weaken the mechanical properties of the product. There is also the possibility of the occurrence of reaction between the oxide and reducing gases of the welding flame. Such a reaction results in the reduction of the cuprous oxide to metallic copper and the production of water vapour within the metal; these in turn give rise to intergranular cracks, porosity, and the usual signs and effects of "gassed" copper.

Deoxidised Copper

In order to overcome these welding difficulties, a grade of copper known as "deoxidised" copper has been introduced. Deoxidisation is effected by adding to the melt, in the final stages of manufacture, a small quantity of some deoxidising element such as phosphorus. The union of the phosphorus with the oxygen in the copper forms a volatile oxide of phosphorus which, when evaporated, leaves the metal free from oxygen. At the same time, a small amount of phosphorus is left in the metal to act as a deoxidiser in welding operations, and this small difference has rendered possible the production of readily weldable grades of copper.

Fluxes

Whilst it is often possible to carry out successful welds on small samples of copper plate without a flux, it is usually necessary to use a flux when welding long lengths of the same copper for constructional purposes.

When using a flux, apply it (preferably in the form of paste) to both sides of the plate. If necessary, also paint the welding rod with the paste before welding commences.

Welding Rods

To improve the fluidity of deoxidised rods, silver is usually incorporated in their manufacture.

Blowpipe Nozzle Size and Flame

Silver excepted, copper conducts heat far more rapidly than any of the common metals. A larger-size nozzle must therefore be fitted to the blowpipe than would be used for an equivalent thickness of mild steel.

It is important to use a strictly neutral flame for copper welding.

Preparation for Welding Sheet Copper

Before starting to weld, see that the metal is scrupulously cleaned.

Fig. 6 shows the type of edge preparation advisable for downhand welding copper. It will be noted that sheet copper of less than 18 gauge thickness can be flanged. The flange should be not less than about twice the thickness of the sheet. The abutting edges may then be melted down with the blowpipe, adding welding rod as and when required.

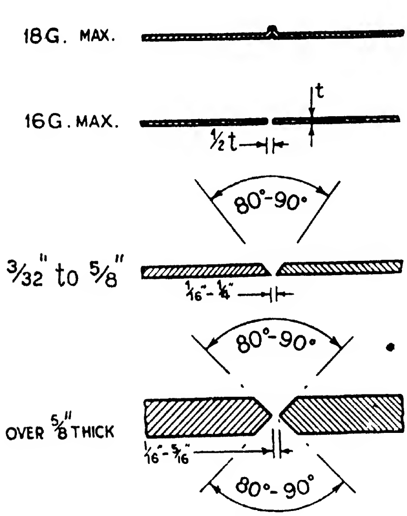


Fig. 6.—Edge preparation for copper downhand welding (*The British Oxygen Co., Ltd.*)

To counteract the effect of expansion, it is necessary, in the case of butt welds, to allow a divergent gap of the order of $\frac{3}{16}$ in. per foot between the plates.

Preheating

The successful welding of copper depends upon the rapidity with which the welding is carried out. This is due to the high heat conductivity of copper. The edges of the copper in the neighbourhood of the joint must be preheated with one or more blowpipes for a short time prior to welding.

In order to conserve the heat and to support the weld deposit, it is sometimes an advantage to use a backing strip when welding from one side only. The backing strip may be a length of angle-iron, or any material of suitable shape and dimensions. In order to prevent extraction of the heat applied to the copper sheet, it is usual to interpose dry asbestos sheet between the copper and the backing strip.

WELDING METHODS

Downhand Welding

For normal thicknesses of copper plate, use the leftward method. Hold the blowpipe fairly steeply in relation to the plate (Fig. 7), so directing as much of the heat as possible to the actual point of welding. Give the blowpipe a slight side to side motion, confining this motion to the weld seam. Do not remove the rod from the flame, but keep it in the molten pool, and see that the inner cone of the flame is kept at about $\frac{3}{8}$ in. away from the surface of the metal.

Fusion Welding Copper Piping

In cases of sanitary and water services piping, it is usual to bronze weld copper pipes wherever practicable, and this is described on page 103, but it may sometimes be necessary to fusion weld them (in which case a copper rod is used).

The method of preparing joints in copper piping is shown in Fig. 8. For butt welds in thin tubes, upset the edges of the pipe and run down the copper by the

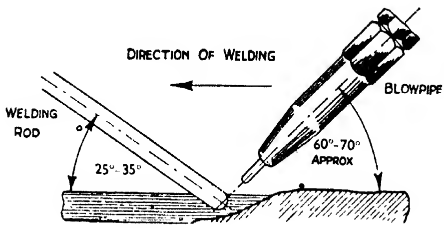


FIG. 7 (*above*).—ANGLES OF ROD AND BLOWPIPE FOR DOWNHAND WELDING COPPER BY THE LEFTWARD METHOD (*The British Oxygen Co., Ltd.*)

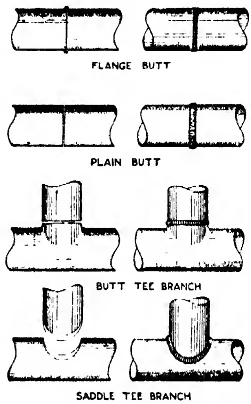


FIG. 8 (*right*).—METHODS OF JOINTING FUSION-WELDED COPPER-PIPE JOINTS (*The British Oxygen Co., Ltd.*)

blowpipe flame. For butt welds in thicker tubes, butt the tubes together, leaving a small gap equal to about the thickness of the tube; the joints may then be welded in the usual manner.

There are two methods of making a T-joint. In the first, a hole is cut in the tube, and the material is then worked out in the usual coppersmith's manner. A butt joint is then made. The second method of making a T-branch is to cut a hole in the pipe and to shape the abutting tube to fit on to the hole. A fillet joint is made at the junction.

Welding Longitudinal Seams on Tanks

When welding longitudinal seams on copper tanks use the leftward, or vertical, method of welding, taking care not to commence welding at the beginning of the seam, but rather commencing at a distance of about one-third of the total length from the end. Then weld throughout two-thirds of the length of the seam in the direction *A–B* (see Fig. 9). Beginning again at the previous starting-point, finish the remainder of the weld in the direction *A–C*.

Two-operator Vertical Welding

Where the seam to be welded can be placed in a vertical position, and, in the case of a vessel, where it is large enough for an operator to work inside, the two-operator vertical method should be used.

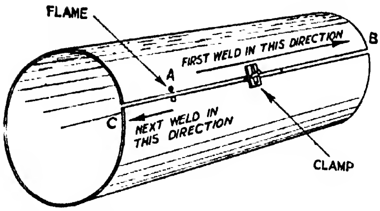


FIG. 9.—METHOD OF WELDING A LONG SEAM IN COPPER (*The British Oxygen Co., Ltd.*)

The two-operator vertical method of welding mild steel is described on page 70. The principles are the same for copper, but the following points of difference should be noted:

Edge Preparation.—For plate of $\frac{3}{8}$ in. thickness and upward the edges must be double-bevelled to give an included angle of 80°. The bevels should not run to a feather edge, but should have a small flat or nose of $\frac{1}{16}$–$\frac{1}{8}$ in. in the centre, to prevent excessive melting.

Size of Nozzles.—One size larger than for vertical welding mild steel of similar thickness.

Angle of Blowpipes.—An angle of 75–90° to the workpiece should be used. The rod angles, however, remain the same as for mild steel.

Movement of Blowpipes.—These are increased to large circles or semi-circles, and are maintained to compensate for the more rapid heat conduction when welding copper as compared with mild steel.

After-treatment of Welds

The most important after-welding treatment is the light hammering of the weld whilst the copper is at a dull-red heat, but never whilst it is "black" hot, otherwise it will become hard and brittle.

Many advantages accrue from a light and careful hammering—excessive grain growth is prevented, the cuprous-oxide eutectic is broken up, and the surface of the weld is strengthened and hardened. This treatment is also recommended when the copper is of the non-deoxidised variety.

If it is desired to hammer a weld flat with the surface of the sheet, heat the copper to a dull-red heat and thoroughly hammer with a planishing hammer until flat, reheating if necessary. After hammering is finished, bring again to a dull-red heat and quench in water.

If it is not possible to hammer the weld at red heat, it may be hammered cold. Cold hammering, wherever its employment is warranted, strengthens the mechanical properties of the metal and consolidates the surface.

SHEET ALUMINIUM

Besides flame brazing (see page 108), aluminium and aluminium alloys can also be fusion welded.

Flux

A flux is essential for welding aluminium to remove the refractory oxide of aluminium (alumina), and to ensure the making of a good, clean joint, free from inclusions. The flux may be applied by either painting both sides of the

metal with flux made into a paste, or by dipping the heated end of the welding rod into the flux, and melting the tuft of flux which adheres to the rod, to form a thin varnish coat along the rod for about 6 in.

Welding Rod

No welding rod need be employed for flanged edges in sheet of 20 gauge thickness and less. For thicknesses up to $\frac{3}{8}$ in. the diameter of the rod should be one and a half times to twice the thickness of the sheet, although in practice rods greater than $\frac{1}{4}$ in. diameter and smaller than $\frac{3}{32}$ in. are rarely used.

Flame

Soft neutral, with, perhaps, a very slight haze of excess acetylene, in order to ensure a non-oxidising flame.

Preparation for Downhand Welding

Sheet aluminium is usually clean except for a very thin layer of oxide, which may be removed by wire-brushing the sheets in the neighbourhood of the weld.

In the case of sheet aluminium of 20 gauge or less, flange it to a depth equal to twice the thickness of the sheet. Butt welding without bevelling is recommended for sheet aluminium of 16 gauge to $\frac{1}{8}$ in. thickness, whilst for greater thicknesses bevelling to an included angle of 90° should be adopted. When the sheet thickness exceeds $\frac{1}{4}$ in., the two-operator vertical method should be adopted wherever possible. This is referred to later.

Tacking

Tacking is sometimes necessary for the maintenance of edges in correct alignment. Where tacking is not employed, take care that the correct taper allowance ($\frac{1}{5}$ in. per foot) is made for heat effect upon the metal.

Nozzle Size

Due to the high thermal conductivity of aluminium, one size larger nozzle is recommended than for downhand welding mild steel of similar thickness.

Welding Method

For downhand welding on sheet up to $\frac{1}{4}$ in. thickness, it will be found that the best technique is the leftward method. The angles of rod and blowpipe are shown in Figs. 10, 11, and 12. As the heat acceleration rate and welding speed increases, it may be found necessary to lower the angle of blowpipe to 25–30° as welding proceeds.

Two-operator Vertical Welding

As previously stated, when the sheet thickness exceeds $\frac{1}{4}$ in., the two-operator vertical method should be adopted wherever possible.

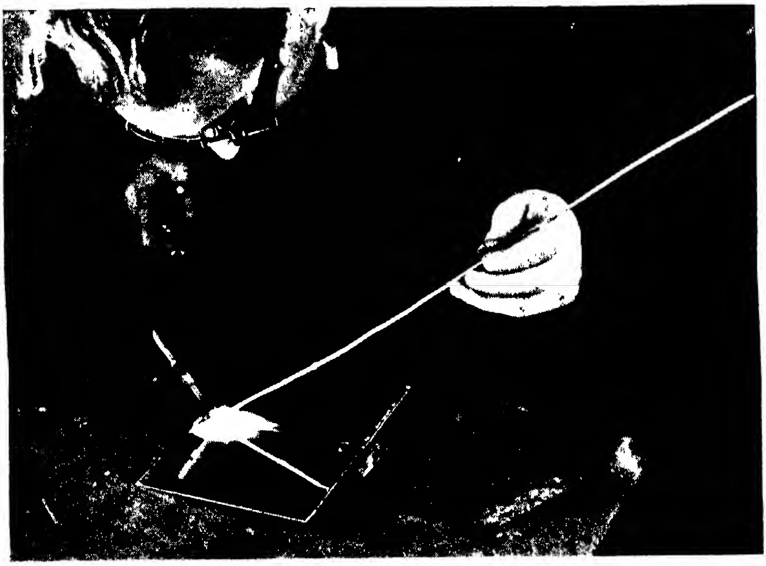


FIG. 10.—DOWNHAND WELDING SHEET ALUMINIUM BY THE LEFTWARD METHOD

Showing angle of rod and blowpipe at commencement of weld, blowpipe being held at about 40–50° and welding rod 30–40°. (*The British Oxygen Co., Ltd.*)

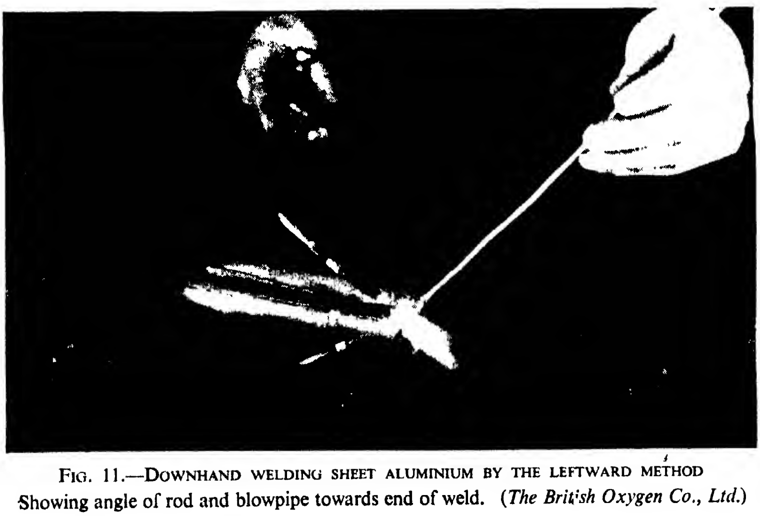


FIG. 11.—DOWNHAND WELDING SHEET ALUMINIUM BY THE LEFTWARD METHOD

Showing angle of rod and blowpipe towards end of weld. (*The British Oxygen Co., Ltd.*)

The two-operator vertical method of welding mild steel is described on page 70. The technique is the same for aluminium, but the following points of difference should be noted.

Edge Preparation.—For aluminium sheet of $\frac{3}{8}$ in. thickness and upward the edges must be double-bevelled to give an included angle of 80°, with a flat nose in the centre of $\frac{1}{16}$–$\frac{1}{8}$ in.

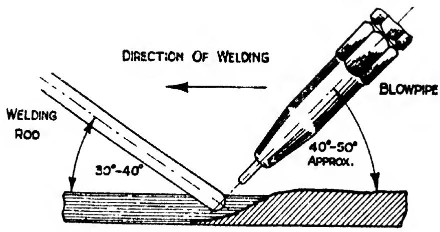


FIG. 12.—ANGLES OF ROD AND BLOWPIPE FOR DOWNHAND WELDING ALUMINIUM BY THE LEFTWARD METHOD (*The British Oxygen Co., Ltd.*)

Size of Nozzles.—One size larger than for vertical welding mild steel of similar thickness.

Angle of Blowpipes.—An angle of 60° to the workpiece should be used. The rod angles, however, remain the same as for mild steel.

Finishing the Weld

When finishing the weld, remove every trace of flux, as the fluxes used for aluminium welding are strongly corrosive in action. Removal of the flux can be effected by washing in warm water and then brushing vigorously with a metal brush; wherever possible, dip the welded article in a warm 5 per cent. solution of nitric acid and immediately rinse in warm water.

A second, precautionary washing, carried out after a few days, may sometimes be advisable.

Heat treatment and mechanical work on the metal brings about a marked improvement in the properties of the weld. As deposited, the aluminium has a cast structure and is rather coarse-grained, but on blowpipe annealing and hammering, the metal is subject to considerable refinement of grain; further, the mechanical properties are rendered equal to, or better than the unwelded sheet.

ALUMINIUM CASTINGS

Aluminium castings will usually be contaminated with oil and grease, which must be removed before a successful aluminium weld can be made.

Edge Preparation

The edges to be welded should be bevelled to an included angle of 80–90° and cleaned with a wire brush. The surrounding surface of the V should also be cleaned to a width of approximately 1 in.

Preheating

Aluminium castings must be preheated. When preheating, the casting should be well supported by mounting carefully on bars or blocks so arranged that the

weight is taken evenly, and at no place can the casting sag or droop when heated. Preheating must be carried out away from draughts.

The preheat temperature will be indicated by the charring of sawdust scattered on the hot casting, or by the melting of a stick of 50/50 solder. The casting must be shielded by sheet metal to prevent the flames of the bunsen or the charcoal used in the preheating furnace from coming into direct contact with the aluminium.

Welding Method

The same principles apply as those involved in the welding of sheet, except that for preheated castings a nozzle one or two sizes smaller than for cold welding should be used.

After welding, the casting must be allowed to cool down slowly and evenly and not hammered, and all traces of flux removed to prevent corrosion.

MAGNESIUM SHEET

Prepare the metal as for aluminium, tacking at very frequent intervals.

Liquid flux should be used for sheet magnesium. Paint the flux on the top and underside of the edges to be welded.

Use a welding rod specified for the class of magnesium to be welded.

Use the same nozzle size as for aluminium of similar thickness.

A neutral flame is required, or with a slight haze of acetylene.

After-treatment

When welding is completed, take very great care to remove all traces of flux. Wash repeatedly with hot water and acid solutions of potassium bichromate. For the purpose of protection against corrosion, all magnesium articles after being welded should be submitted to the special chromating process. Information on this process can be obtained either from the suppliers of magnesium welding rods or from manufacturers of the metal.

To improve the mechanical properties after welding, magnesium sheet may be hammered at 270–300° C.

MAGNESIUM CASTINGS

The welding process for magnesium castings is very similar to welding aluminium castings. The magnesium metal will, however, be found to run more freely.

When preheating the casting, judge the correct heat by rubbing a piece of green wood on the heated surface. Heat will be sufficient when the wood is charred. Care should be taken not to overheat, otherwise burning will take place. A supply of dry sand (not water) should be kept handy in case of overheating and ignition.

Paint the underside of the fracture, if possible, with liquid flux. Heat the welding rod in the flame, dip it in dry powder flux, and then heat the rod again so as to form a flux varnish over the end of the rod.

Reinforce the weld about $\frac{1}{8}$ in. to allow for grinding off.

After-treatment

After welding, the casting must be allowed to cool down slowly and uniformly and not hammered, and all traces of flux removed to prevent corrosion. The chromating process is also applied to castings.

BRASSES AND ZINC-BEARING BRONZES

The welding of brasses and bronzes containing appreciable amounts of zinc involves a special technique. When one of these alloys is heated up to the melting-point there is a copious evolution of zinc fumes, and this is harmful in many respects. There is a loss of zinc; the metal boils, causing blowholes to be formed, and the health of the welder is endangered. By using a carefully regulated oxidising flame a superficial layer of zinc oxide is formed on the bath of molten metal, which protects the remainder of the zinc from the action of the flame, and prevents volatilisation.

The amount of oxygen excess required will depend upon the amount of zinc in the brass or bronze being welded. A simple practical test will determine this amount.

Flame Adjustment

Obtain a small portion of the brass or bronze to be welded and melt it with a neutral flame. It will be found that copious fuming occurs. Cut down the acetylene so that there is an excess of oxygen in the flame, and fuse a further sample of the brass or bronze. Continue decreasing the acetylene supply until fuming ceases. When the experimental melt is cooled, it should be examined for blowholes. If there is any sign of blowhole formation, the acetylene should be still further decreased until the deposit is absolutely non-porous.

At this setting, the inner cone of the flame is almost exactly half the length of the normal neutral cone.

It is important that there should not be too great an excess of oxygen. Too much oxygen will cause the formation of a thick layer of zinc oxide on the molten bath, and destroy the fluidity of the rod.

Nozzle Size

Usually one size larger than for welding mild steel of similar thickness.

Applying Flux

Paint the flux on the top and underside of the edges to be welded and on the welding rod.

Edge Preparation

Sheet.—The preparation of the edges of the joint should be carried out as for mild steel.

Castings.—Bevelling to an included angle of 80–90° is recommended. With preheated castings, the work should be well supported to prevent sag or drooping when heated.

Welding Method

Make certain that the edges of the seam are at red heat and melting before welding commences. The leftward method of welding gives the best results for brasses and bronzes, and once welding has commenced, the flame should not be removed from the job, nor the welding rod from the flame. Hold the inner cone of the flame fairly close to the surface of the weld.

We wish to thank The British Oxygen Co., Ltd., for supplying some of the material for the above article.

BRONZE WELDING

BRONZE welding is allied to the older practice of brazing. In the latter process, a copper-zinc alloy in the granular form is interprosed between the parts to be joined. The whole assembly is then heated to brazing temperature, and the brazing compound flows between the parts, forming a joint on solidification.

In bronze welding, the edges of the metal to be joined are heated by means of a suitable torch, and a bronze welding compound is applied in the form of a bronze welding iron, in a similar way to that employed in the process of oxy-acetylene welding.

Sufficient bronze is deposited to provide a joint of adequate strength. By this means a strong ductile union is easily produced between high-melting-point metals such as cast iron, steel, malleable iron and copper, at temperatures considerably below their melting-points.

Bronze Welding Rods (Standard)

The process of bronze welding can be carried out with almost any copper alloy, but considerations of cost. flowing qualities, strength, and ductility have led to the adoption of one general-purpose alloy for a wide number of uses. This alloy approximates to the 60–40 copper-zinc formula, but minor constituents are incorporated to prevent zinc oxide fuming and to improve fluidity and soundness.

Silicon is the most important of these minor constituents, and its usefulness is apparent in three directions:

(1) It readily unites with oxygen to form silica, and provides a covering for the molten metal which prevents zinc volatilisation. Thus the balance of the constituents of the alloy is retained, and the original high strength of the rod is carried through to the deposit.

(2) The coating of silica readily combines with the flux used in bronze welding to form a very fusible slag which materially assists, by "*capillary*" forces, the "*tinning*" operation, which is an essential feature of any bronze welding process.

(3) By its extraordinary capacity for retaining gases in solution during the solidification of the alloy, silicon prevents the formation of gas holes and porosity in the deposited metal which would reflect very unfavourably upon its strength as a weld, and which would also render the weld susceptible to percolation in applications where a pressure-tight joint is required.

While a carefully controlled percentage of silicon conveys valuable prop-

FIG. 1. — LOCOMOTIVE CYLINDER—(1)
Broken flange prepared for welding.
(*Suffolk Iron Foundry* (1920), *Ltd.*)

erties to the bronze welding rod, the presence of other elements may have a detrimental effect, and in the highest class of bronze welding rods these other elements are reduced to an absolute minimum.

Lead, for instance, is usually present in commercial 60–40 copper-zinc alloys and results in a "boiling" action when the rod is being deposited and in subsequent weld porosity; thus a straight 60–40 alloy is quite unsuitable for this type of work.

FIG. 2. — LOCOMOTIVE CYLINDER—(2)
Close-up view of weld in progress.
(*Suffolk Iron Foundry* (1920), *Ltd.*)

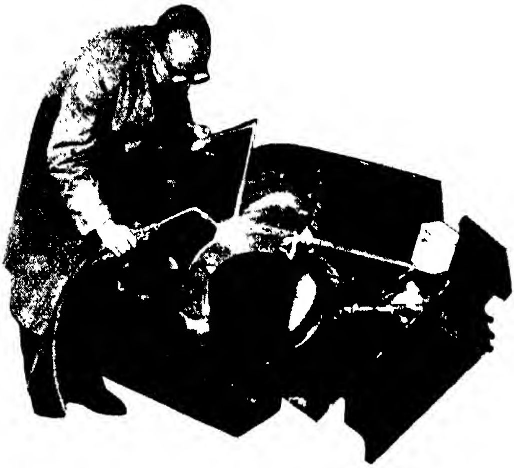


FIG. 3. — LOCOMOTIVE CYLINDER—(3)
General view of welding repair in progress.
(*Suffolk Iron Foundry* (1920), *Ltd.*)

Bronze Welding Rods for Special Purposes

Special circumstances have led to the introduction of bronze rods basically similar to the standard, but incorporating the element nickel. This element gives vastly superior mechanical properties to the bronze welded joint. With a nickel content up to 10 per cent., both the tensile strength and the wear-resisting qualities of the deposit are increased, and this rod is specially suitable for building up worn parts and for surfacing operations.

By the introduction of 15 per cent. nickel the tensile strength of the deposit is still further increased, while the corrosion resistance of the alloy is of a very high order. Furthermore, the deposit is then a good colour match with ferrous metals. This factor is of considerable value in the reclamation of defective castings.

Fluxes

It is essential to use good-quality flux in bronze welding. It was usual in the past to use borax as a flux for brazing operations, but the development of bronze welding has led to the preparation of special fluxes. To obtain highest efficiency from any particular brand of bronze welding rod, it is essential that the flux developed for that rod be used. The purposes of a bronze welding flux are to increase fluidity while depositing, to reduce and remove oxides, thereby facilitating the tinning operation, and to provide a protective slag over the deposited metal. The fulfilment of these purposes depends on the actual properties of the flux and its chemical composition. For instance, it is important that the melting-point of the flux should be slightly below that of the rod, so that its cleansing

action takes place at the crucial moment when it will produce most effective results. The flux should also have a low specific gravity to enable it to float quickly to the surface of the molten deposit.

Applying the Flux

The mode of applying the flux to the welding operation must next be considered. The usual procedure is to dip the heated end of the rod into the powder flux. Sufficient flux adheres to the rod to commence welding, and repetition of the operation at frequent intervals is necessary to proceed with the welding operation. On heavy work and for continuous welding, "*flux-coated*" bronze rods offer a convenient method for introducing a regular supply of flux which is economical and time saving.

These flux-coated rods are higher in initial cost than the bare rods, but this is offset by the savings which accrue through continuous welding. Flux-coated rods are economical in the long run. For example, during a stop for fluxing, while the welder glances to find the tin of flux, his molten pool of bronze freezes, sometimes the white cone of the welding flame wanders away from the welding position or impinges dangerously on the bronze, and always gases are being consumed to no purpose. Moreover, flux-coated bronze rods are more efficient, for just the right amount of flux can be incorporated on the rod, and the haphazard method of dipping into the flux tin is avoided.

The Bronze Welded Joint

Since there is no intermixture of metals, *why does* a bronze alloy, when caused to flow on to a clean steel or cast-iron surface, hold to it with such remarkable tenacity? The complete answer is still unproved; there are many theories called in to fit the facts; some say the joint is due to surface alloying or to surface penetration, or to molecular attraction, or to contact forces. Whatever the exact nature of the joint, there is very tangible evidence of some very great force holding together the different metals.

Tests on Bronze Welded Joints

Some comparative figures taken from tests on untreated "*all-weld-metal*" test-pieces for bronze are shown in the accompanying table.

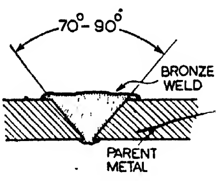


FIG. 4.—CROSS SECTION THROUGH THE BRONZE WELD SHOWING ANGLES OF V PERMISSIBLE

The actual strength of a bronze welded joint taken across the weld is, however, not always in direct relation to the "all-weld-metal strength." Factors affecting the strength of the joint irrespective of the grade of bronze are (*a*) the type of metal joined, and (*b*) the nature of the metal surface. For instance, bronze welded copper plate is usually of the order of 10–12 tons per square inch across the weld, while bronze welded cast iron varies between 5 and 16 tons per square inch, according to the nature of the surfaces joined (the rougher these surfaces the stronger the

weld). The strength of a bronze weld on mild-steel plate reaches 20–25 tons per square inch with the standard bronze rod, while the high-duty bronzes give a stronger joint in each case. These results relate, in each case, to unreinforced weld test specimens.

	Tensile Test. Tons per sq. in.	*Standard Bend Test*	*Elongation. Percentage on 2 in.*	*Brinell Hardness No.*
Standard Sifbronze No. 1	28	Bent cold	25	91
9 per cent. nickel Sifbronze No. 2	36	through 180	20	110
15 per cent. nickel Sifbronze No. 3	41	without fracture	22	115

FUNDAMENTAL BRONZE WELDING TECHNIQUE

The actual method of making a bronze weld varies very little, no matter what type of metal is to be welded. As previously mentioned, it is essential to heat the cleaned surfaces to be joined to a temperature of about 800° C. or dull red, and flow over these surfaces the bronze alloy melted from the rod by a heating flame.

The Types of Flames

The types of flames which can be used are oxy-acetylene, oxy-hydrogen, oxy-coal-gas, or air-acetylene. The oxy-acetylene has the highest flame intensity, and is in most general use, while the use of the air-acetylene flame is limited to work on light-gauge material. The size of the blowpipe flame depends on the thickness and mass of the metal to be welded and upon the extent of preheating. All these factors having been considered, a "soft" type of flame is recommended. The flame should be adjusted to be slightly oxidising in all cases; this is achieved by obtaining the neutral flame, then slightly reducing the acetylene supply; an oxidising flame reduces volatilisation of zinc from the bronze alloy and gives sounder welds.

Preparation of Parts

The preparation of materials to be bronze welded follows normal welding practice. Sections of metal greater than $\frac{1}{8}$ in. in thickness should be V'd out mechanically through their full thickness to give an enclosed angle of between 70° and 90° (see Fig. 4). In addition, the surface of the metal should be cleaned to brightness for $\frac{1}{2}$ in. on either side of the V. For surfacing operations where bronze is to be

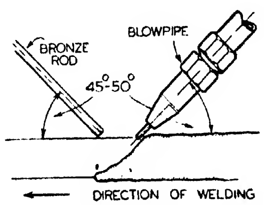


FIG. 5.—ANGLES OF BLOWPIPE AND ROD AND DIRECTION OF WELDING

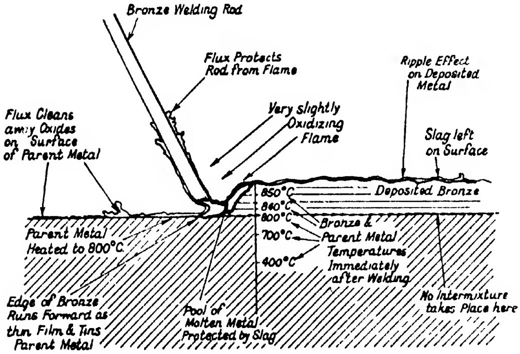


FIG. 6.—PICTURE DIAGRAM OF BRONZE WELDING PROCESS

(*Suffolk Iron Foundry* (1920), *Ltd.*)

deposited, the whole of such areas should be well cleaned, since dirt, oxides, or grease retard "*tinning*." Sand-blasting, filing, grinding, drilling, and chipping are all methods which can be used, but best results are always obtained with chipping, especially when welding cast iron.

Tinning

When the parts to be joined are set up ready for welding and any necessary preheating of the job has been attended to (see later details), welding is commenced by concentrating the heat of the flame gradually upon a circle about 2–3 in. in diameter at the position where it is desired to start. The flame is then converged to one position and some flux is usually sprinkled on the metal. Then the fluxed end of the bronze rod is brought directly beneath the flame and on to the heated section of the V. If the parent metal is at the correct temperature, and only at this temperature, the bronze will spread out over the surface in a thin film like water on a damp surface. This phenomenon is known as *tinning*, since it resembles tinning with tinman's solder. The initial tinning of the parent metals is the whole crux of the bronze welding process, and if the parent metal is too hot or too cold, the bronze rolls in globules like water on a greasy surface, and tinning does not take place. Flux plays an important part in the tinning, since it removes oxides from the surfaces of the metal which are invariably caused by the heating flame.

Building up the Weld

When an initial portion of both sides of the V has been tinned, more bronze is melted into this section, and fusion between the tinning layer and the added bronze is secured by manipulation of the blowpipe. Once good tinning has been secured, any desired strength of bronze may be deposited layer by layer. Thus, as the V is filled, the point of welding moves in a leftward direction along the V. It is often possible to build up a V in material up to $\frac{3}{8}$ in. thick in one operation, but great care is needed to ensure that the rate of deposition of the bronze does not exceed the rate of tinning, otherwise an

unsound weld results. Furthermore, the pool of molten bronze should not be larger than can be conveniently controlled by blowpipe manipulation; in this manner the danger of collapse may then be avoided.

It is also essential to secure tinning and full penetration of weld to the bottom of the V, and the blowpipe is also manipulated to obtain this result. When progressing along the weld seam, the blowpipe is moved from side to side behind the rod in a semicircular manner, though the white cone of the flame must be maintained about $\frac{1}{8}$ in. away from the bronze at all times. Figs. 5 and 6 show the angles of blowpipe and rod, and a picture diagram of the process respectively.

BRONZE WELDING OF CAST IRON

It is an established fact that in the bronze welding of cast iron the greatest advantages of the process are realised. Cast iron is one of the most popular of engineers' materials, and, since it is relatively brittle, fractures often occur. Welding is the logical method of treating such accidents, as castings can only be made from a pattern, and this pattern may often be thousands of miles away from the scene of the fracture. New castings take a long time to procure, and the expense of welding is a small fraction of their cost.

It has been advocated in the past that a metal should always be welded by using a filler rod of identical metal. Cast iron is an exception to this rule, as the fusion welding of this material involves so many precautions, such as expensive and prolonged preheating, careful setting up, and selecting of rods. After fusion welding, also, there is generally distortion of surfaces owing to "grain growth," so that expensive machining is necessary. With bronze welding, however, the operation is much simplified, and extremely reliable joints may be made without much preheating and without distortion, while some castings may be welded without even dismantling them from the machine.

Another important factor in favour of bronze welding castings is that bronze welding rods have such a variety of purposes that they are often stocked in "out-of-the-way" places, and it is in such places that accidents to cast-iron machinery often occur and urgent repairs must be made.

A further use for the bronze welding of castings lies in the reclamation of castings which would be otherwise scrapped in the foundry, because they contain blowholes or shrinkage flaws. Valuable castings are often saved by filling in defects with bronze weld metal; for instance, a large foundry in the north of England saved a large compressor casting of considerable value by bronze welding with White Sifbronze No. 3. It was noteworthy that this casting successfully withstood a pressure test of 150 lb. per square inch without the slightest sign of seepage about the weld. The White Sifbronze rod was used, and this made the weld difficult to detect.

For fabrication purposes it is sometimes necessary to join cast iron to steel or copper, and bronze welding is the only means by which this can satisfactorily be achieved. It must also be stressed that, whereas a cast-iron fusion weld is at least as brittle as the parent metal, a bronze weld, on the other hand, will with-

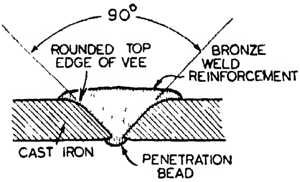


FIG. 7.—CROSS SECTION THROUGH BRONZE WELDED CAST IRON, SHOWING V-ing TECHNIQUE

stand considerable deformation before fracture, and therefore, when a bronze weld cools, it is not so likely to give way under cooling stresses or in after service.

PROCEDURE FOR BRONZE WELDING CASTINGS

Castings to be bronze welded are V'd out through their full section thickness, preferably by chipping. By drilling holes breaking into each other along the line of a crack, and arranging that the holes do not quite penetrate the wall thickness, the chipping operation can be speeded up. It is advisable to leave a gap of about $\frac{1}{16}$ in. at the bottom of a V'd crack, since this gives room for expansion of the sides inwards during welding, and fracture elsewhere may thus be prevented. For about half an inch on either side of the V, the parent metal should be cleaned to brightness. When welding, the bronze should be built up over this cleaned surface to give good reinforcement. If the top edges of the V are rounded off, this reinforcement deposition is simplified, as the sharp corners do not then become overheated (see Fig. 7).

When a fracture leads to the edge of a casting or to a hole 1 in. or more in diameter, bronze welding should always proceed from the extreme end of the crack towards this hole. In the case of "*tied*" welds, i.e. where a crack does not run to an edge, special care must be taken.

"Tied" welds are subjected to intense strains due to expansion on heating and to contraction on cooling. Fractures of this type should be V'd out in the usual manner and a small hole drilled approximately $\frac{1}{2}$ in. beyond the visible ends. Bronze welding should then commence in the centre of the fracture and proceed, with particular care to avoid overheating the parts, taking in each small hole in turn. Slow cooling with this type of weld is most important for success.

In all types of bronze welding, and especially on cast iron, it is advisable to pause for a few minutes after completing the first 2 or 3 in. of weld; this pause allows time for complete solidification and prevents subsequent cracking in the deposited metal.

Preheating

In many cases preheating before bronze welding can be eliminated; this applies in cases where the parts are free to expand and contract, and no serious stresses will result.

Where a casting is large or of intricate design, partial preheating should be arranged. This can be conveniently carried out with a large blowpipe, gas bunsen, or blowlamp.

In the repair of a third type of casting, particularly where the weld is "tied," more extensive preheating is necessary; in these cases it is advisable to preheat

the casting in a muffle. Such muffles may be permanent, as when large numbers of castings of similar type are being dealt with, or temporary, for accommodating a variety of different shapes and sizes of castings.

Another great benefit of preheating is that, by initially raising the temperature of a casting or castings, the bronze welding may be carried out more quickly, with greater certainty, and with a saving of welding gases and operator's time.

Welding Castings

The welding of castings follows exactly the normal bronze welding procedure detailed on pp. 95–97. It will always be found, however, that even good cast iron is more difficult to "tin" than steel, for instance. This is in a large measure due to the presence in the metal of *graphite flakes*, which retard the spread of the molten bronze over the surface. Where the grade of cast iron is poor or the metal is badly oxidised or burnt, this becomes a serious problem, but vigorous rubbing of the heated cast-iron surface with the bronze rod and a generous supply of flux greatly assists in overcoming this difficulty. Figs. 8–12 illustrate clearly the stages in bronze welding a casting.

Special Precautions

There are several factors which have considerable bearing on the success or failure of a bronze-welded casting. Attention to preliminary details is amply repaid by a sound, well-finished job; for instance, it cannot be too highly

FIG. 8.—LARGE CAST-IRON PUMP HEAD, SHOWING FRACTURED SECTION
(*Suffolk Iron Foundry* (1920), *Ltd.*)

FIG. 9.—CAST-IRON PUMP HEAD, PREPARED FOR SIFBRONZE WELDING
(*Suffolk Iron Foundry* (1920), *Ltd.*)

FIG. 10.—CAST-IRON PUMP HEAD, WELDING IN PROGRESS
(*Suffolk Iron Foundry* (1920), *Ltd.*)

FIG. 11.—CAST-IRON PUMP HEAD, COMPLETED SIFBRONZE WELDS
(*Suffolk Iron Foundry* (1920), *Ltd.*)

stressed that cleanliness is of the utmost importance. Certain types of castings become oil-soaked in service, and, whilst mechanical cleaning appears to be satisfactory when heat is applied to castings of this type, oil appears to be ejected from the pores of the casting, and this prevents "tinning." If such a casting be heated for a period at a low temperature (200–300° C.), this trouble will be eliminated. Sudden application of local heat to a dead-cold casting may result in immediate fracture, and no welding should commence without at least warming up the casting.

Bronze weld metal loses strength rapidly at temperatures exceeding 300° C., and no bronze welds should therefore be made on castings which are subjected to temperatures higher than 250° C. in service. The repair of shattered castings often requires the replacement of missing pieces. A steel patch or the broken-out portion should be inserted and welded last of all. In the preparation of this part $\frac{1}{16}$-in. clearance all round should be allowed.

Castings of intricate shape and varying thicknesses, such as internal-combustion engine heads, sometimes become fractured for no apparent reason; careful study may reveal that such cracks are the result of locked-up stresses in the original casting. Full preheating, welding, and annealing are the only means of stress-relieving castings of this type.

Cooling after Welding

Slow cooling after welding is of paramount importance, no matter whether full, partial, local, or no preheating has been employed. The time necessary for

FIG. 12.—CAST-IRON PUMP HEAD, CLOSE-UP VIEW OF COMPLETED SIFBRONZE WELDS
Note the $\frac{3}{4}$-in. diameter mild-steel stay, Sifbronze welded as additional support.
(*Suffolk Iron Foundry* (1920), *Ltd.*)

cooling should be graded according to the extent of the preheating; on one hand, some unpreheated castings merely require protection from cold draughts of air, and, on the other hand, fully preheated articles require cooling in the preheating furnace to be spread over at least twenty-four hours.

Bronze weld metal is always soft and machinable, and surplus is easily removed by all normal machining methods.

Versatility of Bronze Welding

One outstanding reason for the popularity of bronze welding in engineering workshops, garages, and among maintenance engineers is its versatility. The same rod and process can be used for the welding of steel, copper, brass, malleable iron, stainless steel, and for surfacing operations on these metals.

Bronze Welding Steel

The fabrication of sheet-steel parts for production work is usually accomplished by other methods of welding, but even in this sphere there are jobs which can be done best by bronze welding. For instance, in attaching small lugs, rings, tubes, etc., to thin sheet steel in aircraft construction, bronze welding is almost invariably used. Of great value in this instance is the fact that, by bronze welding, the intrinsic properties of the steel, often obtained by heat treatment, are not destroyed, since the bronze-welding temperature is below critical change points in the steel. Also, in cases where distortion must be avoided, the bronze welding of steel is often employed, e.g. the welding of circular and band saws, fabricating hinges, and hydraulic cylinder attachments.

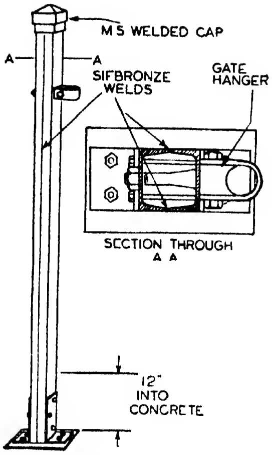


FIG. 13 (*above*).—STEEL GATE-POST 7 FT. OVERALL, FABRICATED BY BRONZE WELDING (*Suffolk Iron Foundry* (1920), *Ltd.*)

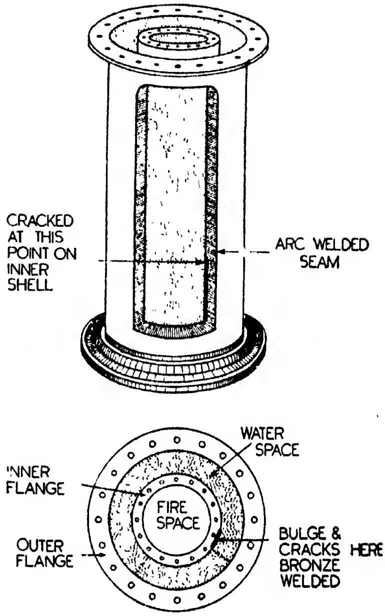


FIG. 14 (*right*).—STEEL HEATING BOILER REPAIRED WITH BRONZE WELDING (*Suffolk Iron Foundry* (1920), *Ltd.*)

Fig. 13 is a sketch of a fabricated steel gate-post. For repair work on steel, bronze welding is often used, and Fig. 14 shows a steel heating boiler repaired by this means.

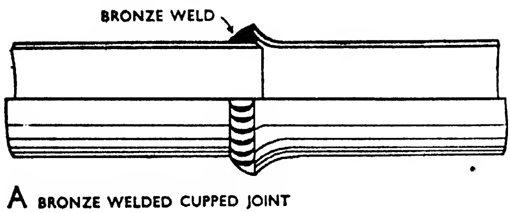
The usual method of fusion welding low-alloy structural steels often leads to embrittlement, but if high-duty bronze, such as the 9 per cent. or 15 per cent. nickel Sifbronze, is used, embrittlement is prevented, and a join up to 35 tons per square inch in tensile strength and with good elongation is thus made.

Bronze Welding Malleable Iron

Malleable iron is a special type of cast iron produced by heat treatment which gives it some of the ductility of steel. Since fusion of this metal destroys its malleability, bronze welding should always be used for making important joints in this metal. In the welding of pipelines using malleable fittings and steel tubes, bronze welding is often used. Similarly, in the rear axles of commercial vehicles, malleable differential casings and other parts can be fabricated and repaired by bronze welding.

Bronze Welding Copper

Bronze welding on copper finds most favour in the welding of joints on light-gauge pipes for hot and cold water and soil pipe services. In this manner



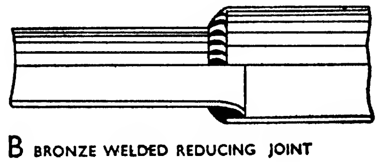


FIG. 15.—BRONZE WELDED BUTT JOINTS IN COPPER PIPE

A. Bell-type butt joints.
B. Reducing joint.

a neat, strong, permanent leak-proof joint can quickly and economically be made, and fittings may to a large extent be dispensed with. Fig. 15 is a sketch showing the usual type of bronze-welded short bell butt joint in copper pipe, though butt joints are sometimes used. The bronze joint, properly made, is quite elastic and stronger than the pipe wall. In some cases bronze welds cannot be used when the material carried in the pipes is one which leads to electrolytic action between the bronze and copper at the joint, but if a good reliable bronze rod, such as Sifbronze, is used, this action may be neglected in practically all cases.

When it is necessary to join very light gauge brass fittings to copper pipes, a modified copper alloy, such as "Sifcupron," is easier to apply than the standard bronze rod, although the same technique is used. This type of joint is cheaper than silver soldering, and as no flux is necessary, it is very easily plated with nickel or chromium.

Other applications of the bronze welding of copper are in the fabrication of food kettles, copper ball floats, model locomotive boilers, gas water-heaters, etc.

Bronze Welded Brass

The joint between the all-purpose bronze and commercial yellow brass is more of a fusion weld than any other type of bronze weld. This is because of the closeness of the melting-points of the two alloys. Nevertheless, when bronze welding such brass, it is only necessary to obtain incipient fusion of the parent metal before flowing on the bronze to give maximum weld tensile and bend strength. The application of this joint is almost confined to fabricating brass piping (butt joints are the rule), but other similar joints are used for joining heavy flanges to copper pipes and steam pipes.

Bronze Welding Stainless Steel

The fusion welding of stainless steel requires a special technique, but when bronze welding is used, the normal bronze welding technique may be followed.

For fusion welding, too, it is essential that both filler rod and parent metal be of the same alloy, and that both are what are known as "weldable" varieties.

In practice, especially in repair work, these conditions are seldom obtained, and though at first sight after completion a fusion weld may seem satisfactory, "weld decay" sets in during service, and the welded part may fail. It is because of this fact that bronze welding is much safer for stainless steel, since the possibility of weld decay does not occur. Furthermore, if colour match and high corrosion resistance of the bronze weld metal are required, a special bronze rod such as White Sifbronze No. 3 may be employed. A firm of container manufacturers in the north, who had previously rejected stainless-steel work, were shown how successful bronze welding on this material could be, and they have now adopted this practice for the fabrication of urns, sinks, counters, sills, stirring equipment and similar articles for cafés, restaurants, hotel kitchens, and milk bars.

Bronze Welding Other Alloys

In general, bronze welding may be applied to practically all metals and alloys with the same or a higher melting-point than the bronze itself. This classification includes the various copper-zinc and copper-tin alloys, nickel and nickel alloys, monel metal, nickel-clad steel, high- and low-carbon and alloy steels, various plain and alloy cast irons.

Galvanised Iron

Bronze welding is the only satisfactory method of joining galvanised-iron articles, such as pipes, fan ducts, ventilating cones, and sheetwork. By bronze welding, the protection which is afforded by the galvanised coating is not destroyed. In all cases the technique is similar.

Aluminium and its Alloys

Aluminium and its alloys, on the other hand, cannot be satisfactorily bronze welded, since the heating of this metal produces an extremely refractory skin of oxide which can only be broken up when, as occurs in fusion welding, the metal beneath this skin is melted. For this reason, too, aluminium bronzes are difficult to weld. If, however, aluminium flux be mixed with standard bronze welding flux for this work, good results on aluminium bronze can be obtained.

Brasses containing Lead

Brasses containing lead are also difficult to weld, but bearing alloys containing lead can be built up, using a modified bronze welding technique and a special lead containing rod.

SPECIAL BRONZE WELDING APPLICATIONS

There are numerous instances where bronze welding can be used to advantage, and in the following paragraphs several of the special applications will be described.

Tipping Tools

The all-purpose bronze alloy is made into thin strip form for applications where difficulty of access or lack of space prevents the introduction of the alloy in rod form. Chief amongst these applications is the fixing of tungsten carbide tips to medium carbon-steel shanks for lathe-cutting tools, special boring cutters, and so on. These jobs are very similar to true brazing, but it has been found that the all-purpose bronze alloy developed for bronze welding gives a much stronger joint than the older types of brazing wire or spelter. Fig. 17 shows a lathe tool tipped by means of Sifbronze strip alloy.

Ornamental Ironwork

One of the most fascinating fields of modern metal work is the assembly of iron, steel, and brass into ornamented grilles, balustrades, gates, and candelabras by welding, and much of this work is done by bronze welding, as Fig. 16 shows. Here the fact that dissimilar metals may be joined to each other without distortion or hard joints by bronze welding is a factor which adds to the popularity of this process. Furthermore, bronze welding on ornamental work very rarely requires dressing. Welds can easily be produced which blend with the lines of the finished article, and considerably enhance its appearance.

Bronze Surfacing

Bronze surfacing, which implies the deposition of a surface of bronze on wearing parts in a similar manner to bronze welding, is a process which has become very popular in recent years. For instance, a cast-iron lathe saddle may wear quickly, and yet if this saddle be surfaced with the standard bronze weld

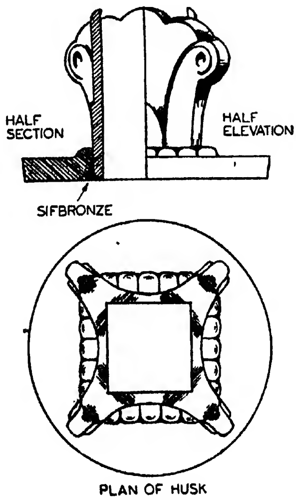


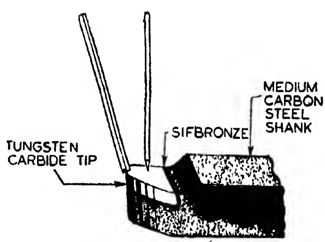
FIG. 16 (*left*).—CAST-IRON ORNAMENTAL HUSK ASSEMBLED BY BRONZE WELDING

(*Suffolk Iron Foundry* (1920), *Ltd.*)

FIG. 17 (*below*).—LATHE TOOL TIPPED BY USING SIFBRONZE STRIP

Note the tools used for seating the tip while the bronze is molten.

(*Suffolk Iron Foundry* (1920), *Ltd.*)



metal, its life is greatly increased at a trifling expense, and, moreover, the bronze, as it in turn wears away, may be replaced time after time. The special bronze containing 9 per cent. of nickel and some manganese is specially suited to this work, since it is somewhat harder and provides more of a bearing surface than the standard bronze. Worn brake drums, valve seats, conveyor flights, pistons, impellers, steel shafts, pump linings, bearings, hubs, beater bars, and all reciprocating slides may be repaired by this process.

In some cases new articles are surfaced with bronze before being put into service, and thereby the wearing life is substantially increased. Sand-blasting is the preferred method of treating a surface before depositing bronze.

When Surfacing Steel

There is one factor which must be borne in mind when surfacing steel, and it is due to the fact that with repeated applications the bronze tends to penetrate and disrupt the surface of the steel and in the end cause failure. If, when applying a second layer of bronze to steel, the temperature is kept low and the base layer of bronze is little disturbed, this cause of failure is avoided.

Economies of Bronze Welding

As has been previously explained, the wide value of the bronze welding rod as a versatile welding medium for a thousand different types of jobs is the key to its success. Bronze welding rods compared, say, with steel rods are much more expensive. It is not, however, so much the initial cost of rods as the waiting time, labour time, and materials for preheating, gases consumed, etc., which decide the final cost of a welding job; when all these factors are considered, bronze welding will be found very economical in the long run.

In many cases the total cost of a bronze welded repair is but a fraction of that of a new article. This is especially true of repair work in maintenance shops and garages. A breakdown in a factory may mean a loss of thousands of pounds in waiting time if a quick repair cannot be made. Similarly, the time during which his car is waiting for a new cylinder block may involve a business man in heavy loss through missed contacts or appointments, whereas a quicker bronze welded repair by a man on the spot will save the day. It is in the light of these examples which occur by thousands every day that the true value of bronze welding should be reckoned.

The above matter was compiled with the kind assistance of Suffolk Iron Foundry (1920), Ltd.

FLAME BRAZING OF ALUMINIUM

ALUMINIUM flame brazing is a process of brazing aluminium assemblies using a flame resulting from the combustion of oxygen and acetylene gas directed through a blowpipe on to the brazing material, which is usually in the form of a metal rod. The rod melts, and the driving action of the flame, together with the property of capillary attraction, causes the molten metal to flow into the joint. It is necessary to use a suitable flux with this method.

Flame brazing of light-gauge aluminium has numerous applications in light engineering and the manufacture of domestic utensils. These include the fixing of spouts and handles to domestic ware, indication tabs and discs for aircraft and other tubing, and in the manufacture of wave-receiving equipment for wireless or radio-location units.

Thick sections of aluminium up to ½ in. thickness may also be flame brazed with good results, although the procedure is slightly different. This process is used in the manufacture of aluminium window frames and the assembly of bus-bars. Flame brazing may also be carried out on aluminium-magnesium alloys, but the difficulties increase as the magnesium contents exceed 2 per cent.

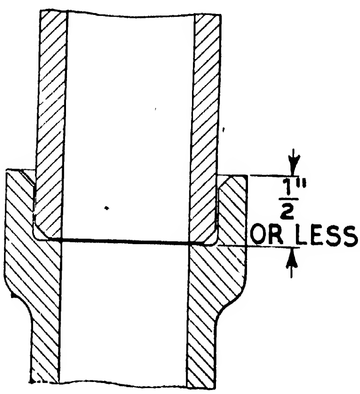


FIG. 1.—CORRECT PREPARATION FOR SOCKET JOINT

Preparation of the Parts

Commercially pure aluminium sheet can be brazed without removal of the normal surface shine or oxide film, provided the metal is new and clean and is free from grease or other matter. Degreasing can be carried out by dipping the part in an organic solvent, such as carbon tetrachloride or trichlorethylene (see article on page 252). Aluminium alloys must have the surface oxide removed by scratching the surface with steel wool, wire brush, or a file. The edges of the aluminium should be smooth and projections removed by filing.

Socket-type joints should have the short inserted portion restricted as much as possible (preferably less than

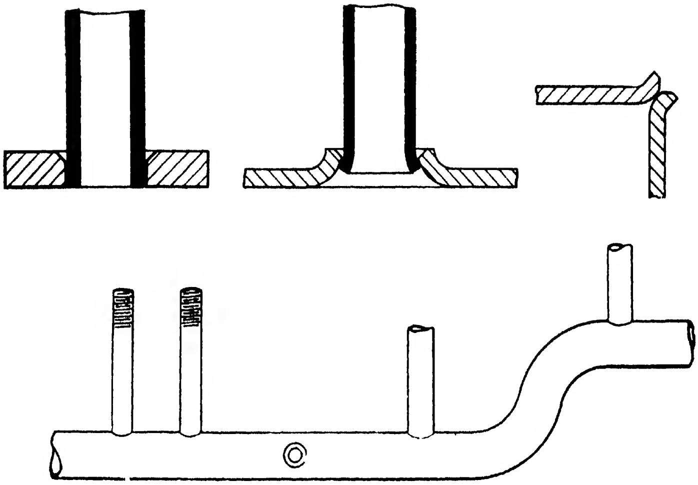


FIG. 2.—EXAMPLES OF JOINTS SUITABLE FOR BRAZING

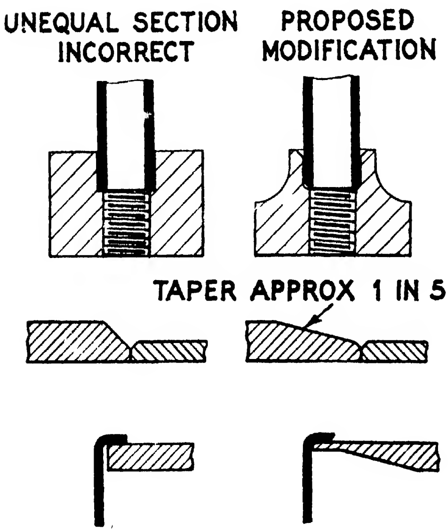


FIG. 3.—MODIFICATION OF JOINTS TO PRODUCE EQUALITY OF SECTION

Wherever possible, admitting or contacting surfaces should be brought to equal thickness or equality of section.

½ in.), although the outer socket can be left square on the end. However, it is an advantage to bevel this end to 45° for half its thickness, to provide a trough to receive the filler metal; the inserted end can also be treated in a similar fashion (see Fig. 1). Other joints which can be satisfactorily flame brazed are shown in Fig. 2. Wherever possible, abutting or contacting surfaces should be brought to equal thickness or equality of section (Fig. 3).

Complicated sheet work should be held in position by means of rivets or spot welds in preference to jigs, which, unless specially designed, are not very satisfactory. Press fits or very close tolerances are not desirable, since diffusion is likely to render the brazing metal rather less fluid, resulting in incomplete penetration. Slight clearances are advisable to enable complete penetration of the brazing metal and flux. The amount of clearance should be determined by trial, but as a general rule the wider the lap, the greater the amount of clearance necessary.

Choice of Brazing Metal and Flux

A satisfactory brazed joint can be obtained by the use of a filler rod composed of 10–12 per cent. silicon-aluminium alloy. Copper-silicon-aluminium rods may also be used, and these have a much lower melting-point. It is not advisable, however, to use them for articles which may have to meet with corrosive conditions.

Borax-base fluxes are not suitable for aluminium flame brazing, and it is advisable to use one of the proprietary fluxes specially compounded for aluminium brazing, one such flux being the aluminium brazing powder made by the British Oxygen Co., Ltd.

The Equipment

A standard welding blowpipe (see page 64) with two-stage type regulators is used to give a steady flame. The power of the blowpipe used is a little less than

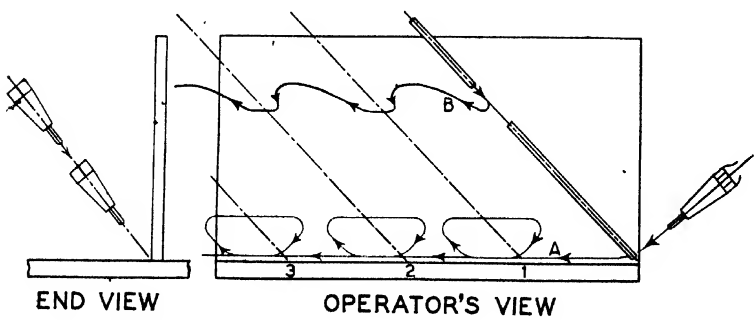


FIG. 4.—BLOWPIPE AND ROD MANIPULATION. *A*, BLOWPIPE MOVEMENT. *B*, ROD MOVEMENT. 1, 2, 3, POINTS OF APPLICATION OF ROD

would be used to fusion weld the same part. For very small assemblies a nozzle the same size as would be used for fusion welding will be satisfactory. For large assemblies a nozzle one size larger than that used for fusion welding should be used.

The blowpipe flame should be adjusted to a neutral condition. After lighting the acetylene flame, the oxygen valve should be opened slowly until the inner cone is well defined, but with a slight haze or mistiness around its point. This haze should be as small as possible, and if the cone should appear "ragged," it is burning with an excess of acetylene. Adjusting the flame in this manner is desirable, because as the nozzle becomes hot the flame tends to revert to slightly oxidising conditions, so losing the mistiness. This acts as an indication to the operator, who should immediately rectify or readjust the flame when the haze disappears.

The Brazing Procedure

The joint should be preheated with the envelope of the flame, the inner blue cone being held about 2 in. clear of the metal surface. The blowpipe and rod are held at approximately the same angles as for fusion welding. The end of the rod is then heated and dipped into the flux tin. The small amount of flux adhering to the rod is then touched down on the surface of the joint to check the temperature. At the correct temperature the flux will begin to flow smoothly and rapidly forward along the joint. A small amount of filler metal should be added and the rod withdrawn. It is important that no filler metal should be added until the flux can be seen flowing, induced by the heat of the work. When the rod metal begins to flow, the blowpipe is moved towards the joint until the inner cone is almost at the normal welding position. At the same time, and in conjunction with this movement, it is moved rapidly forward with a flicking action, drawn away, and brought back to the original position, but at a point opposite that to which the molten metal has travelled, for the movement to be repeated (Fig. 4). This operation is repeated as the brazing proceeds, except that additional flux is not required for short seams or joints. Too much flux masks the operation and is not beneficial.

Removal of Flux

All flux should be removed after the brazing operation to prevent possible corrosion. This can be done by dipping the part into water while it is still hot, afterwards scrubbing the part with a stiff bristle brush during immersion in hot soapy water and finish by rinsing the article in clear water.

A more effective method is to dip it into a solution of 5–10 per cent. nitric acid and lightly scrub afterwards, washing it in clear running water.

Brazing of Butt Joints in Thick Aluminium Strip

The ends and surfaces of the plates should be cleaned either by scrubbing with wire wool and finishing with a file or by treating with a 10 per cent. solution of caustic soda.

The gap in the plates to be joined should be such that it almost closes by expansion of the parent plates during preheating, though the light of the blowpipe flame should be visible behind the gap immediately prior to brazing.

For brazing ½-in. thick aluminium up to 6 in. or 8 in. wide, a blowpipe nozzle consuming 25 cub. ft. of each gas per hour should be used.

The brazing operation may be carried out generally with a neutral flame, but sometimes, depending on the conditions of the aluminium surface, better joints are obtained with an excess acetylene flame. To obtain this the oxygen valve on the blowpipe should be turned back and the total length of the acetylene feather, when measured from its tip to the orifice of the blowpipe, should be twice that of the inner cone.

The joint should be preheated, using the "envelope" of the flame for approximately three minutes. When the flux flows freely in liquid form, the metal from the rod should be added.

Butt joints can be made in any position, but with vertical joints it is desirable, where possible, to carry out the brazing in an upward direction, keeping the amount of flux to a minimum.

T and fillet joints carried out in the downhand position present no difficulty, but in the overhead position the vertical member tends to take up brazing temperature before the horizontal member. This can be avoided by using a larger nozzle and increasing the preheating time to four or five minutes.

We are indebted to The British Oxygen Co., Ltd. for supplying the information upon which this article is based.

SOLDERING AND BRAZING OF STAINLESS STEEL

SOLDERING and brazing are practicable and often convenient methods of making satisfactory joints in stainless-steel equipment. Stainless steels are used where their enhanced resistance to corrosion is of advantage, so that the suitability of soldering or brazing for any particular application should have regard to the condition of usage, both in respect of the corrosion resistance of the joining alloy and the effect of the process heating on the properties of the stainless steel. This latter is of particular importance in the case of brazing.

Soldering

All types of stainless steel can be soldered with the normal grades of soft solder. As with all other metals, the surfaces to be soldered must be

FIG. 1.—BRAZING OF LACING WIRES ON STAINLESS-STEEL TURBINE BLADES. (*C. A. Parsons & Co., Ltd.*)

clean. A machined surface is quite suitable, but with polished steel the surfaces may have to be roughened by filing or rubbing with emery-cloth. Alternatively, the surfaces may be roughened by etching, for which a suitable solution is one containing two parts of hydrochloric acid and one part of nitric acid. The solution should be allowed to act for 5–10 minutes and then washed off.

Fluxes containing resinous compounds are not satisfactory. Suitable fluxes are acid in character, and those most commonly used are a solution of zinc-chloride containing free hydrochloric acid, and concentrated phosphoric acid. There are several proprietary fluxes of these types.

In order to prevent corrosion of the metal parts, all traces of flux should be removed, after soldering, by washing the joint in hot water, which may with advantage contain soda or lime.

Brazing

All stainless steels may be brazed with ordinary copper-zinc brazing alloy, using borax as a flux.

The surfaces to be joined should be thoroughly cleaned, and whilst being heated should be effectively protected by the flux coating from oxidation. If the surface of the stainless steel becomes oxidised, a highly refractory oxide is formed which will interfere with the continuity of the joint. The steel should not be heated to a temperature higher than that necessary to obtain adequate fluidity of the brazing alloy, and for this reason hard or silver solders are generally preferred, as they melt at a lower temperature than the copper-zinc alloys. For these latter alloys a fluoride-type flux may be used.

One of the most interesting applications of brazing is the process known as "furnace brazing". This depends on capillary action, i.e. the tendency of a liquid to be drawn between two surfaces which are sufficiently close together. This process is described in some detail in the next section of this work.

We are indebted to Messrs. Brown, Bayley's Steel Works, Ltd., for supplying the information given above.

FURNACE BRAZING

FURNACE brazing is being used to an ever-increasing extent in the fabrication of metal assemblies. It has the advantage that many joints on separate components can be made at the same time.

It is a method of joining components by the use of copper or other suitable brazing alloy, utilising the property of capillary attraction, i.e. the fact that if a pool of liquid, or molten brazing metal, is brought near to two contiguous surfaces, it is drawn into the space between them.

The chief application of the process has been the brazing of mild steel with copper, but many other metals may also be successfully furnace brazed; if desired, the brazing alloy can be brass, silver-solder, or other alloys, depending on the temperature to which the parent metal can be safely heated.

In certain cases, i.e. the furnace brazing of metals containing a large amount of chromium or zinc, satisfactory results are obtained only if a flux is used, but this is not necessary with the majority of metals.

Carbon and alloy steels after brazing may, if desired, be submitted to any of the usual heat treatments, such as carburising, annealing, normalising, hardening, and tempering.

Furnace brazing in many cases has advantages compared with alternative methods of manufacture, such as welding, torch brazing, soldering, and riveting, or machining from the casting, forging or bar stock. Such advantages may be listed as absence of distortion and locked-up stresses, high strength, uniformity from piece to piece, clean finish, and low cost. Further, it is a process which lends itself admirably to modern "in-line" production methods.

Assembly of Components

The success of furnace brazing is dependent mainly on three factors: the design of the joint, its tolerances, and correct application of the brazing alloy.

The distance which the brazing metal will flow in a joint due to capillary forces is in inverse proportion to the width of the gap and also varies according to the surface condition of the components. Molten copper will flow more readily on a slightly rough surface than on a highly polished one, and a normal machined surface is found to be very satisfactory.

When components having ground or polished surfaces are to be furnace brazed, it is occasionally found desirable to roughen the joint surfaces by means of light shot blasting. The joint surfaces should also be free from oxide or scale, and any lubricants, other than small quantities of machine oil, should be removed.

Particular attention must be paid to the fit of the joint. For steel brazed with

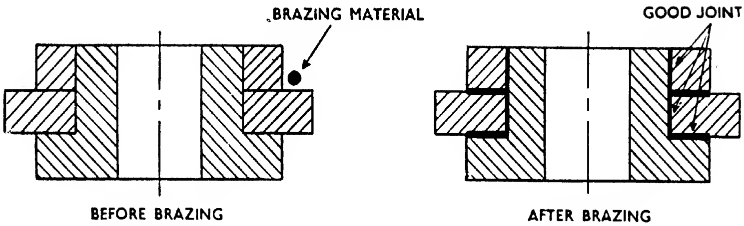


FIG. 1.—DIAGRAM SHOWING THE TYPE OF FIT NEEDED TO PROMOTE CAPILLARY ACTION

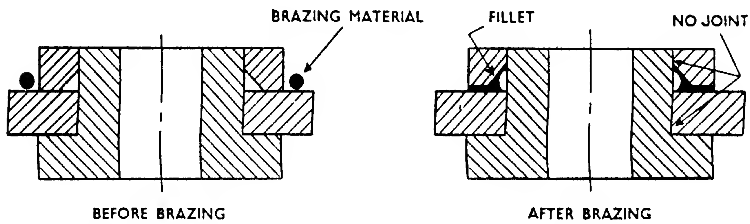


FIG. 2.—INTERNAL CHAMFERS AND OTHER LARGE CLEARANCES INTERFERE WITH THE CAPILLARY ATTRACTION OF MOLTEN COPPER AND CAUSE FAULTY BRAZING *(Birlec, Ltd.)*

copper, optimum results are obtained between the limits of 0·001-in. interference and 0·002-in. clearance. In any case, the clearance should not exceed 0·004 in., or there is difficulty in retaining the molten copper in the joint (Figs. 1 and 2). With a normal machined finish it has been found that the best results are obtained with a clearance of from 0·000 in. to 0·002 in. on the diameter; but for a ground or polished surface, the clearance should be within the upper regions of this scale. For non-ferrous metals, somewhat larger clearances are usually desirable.

The assembly must be held together sufficiently firmly to allow it to be conveyed through the brazing furnace without relative movement of the component parts (Fig. 3). This may be accomplished in many ways, the simplest of which is the use of a slight interference fit in the joint. Other methods are the use of location pegs or spot welding. A typical example of a suitable assembly is shown in Fig. 4.

Special care should be taken, when applying the brazing alloy, with a view to easy inspection of the joint after completion of the brazing operation.

The brazing alloy may be applied in the form of wire rings, paste, or strips, depending on the shape of the component and the disposition of the joint. It may be put either in the joint or in close proximity, so that when melted it will run into and fill the clearance of the joint (Fig. 5).

Box-shaped components, normally of unsuitable shape for brazing, can sometimes be assembled and brazed in a flat condition and subsequently folded or bent to their final shape after brazing is completed.

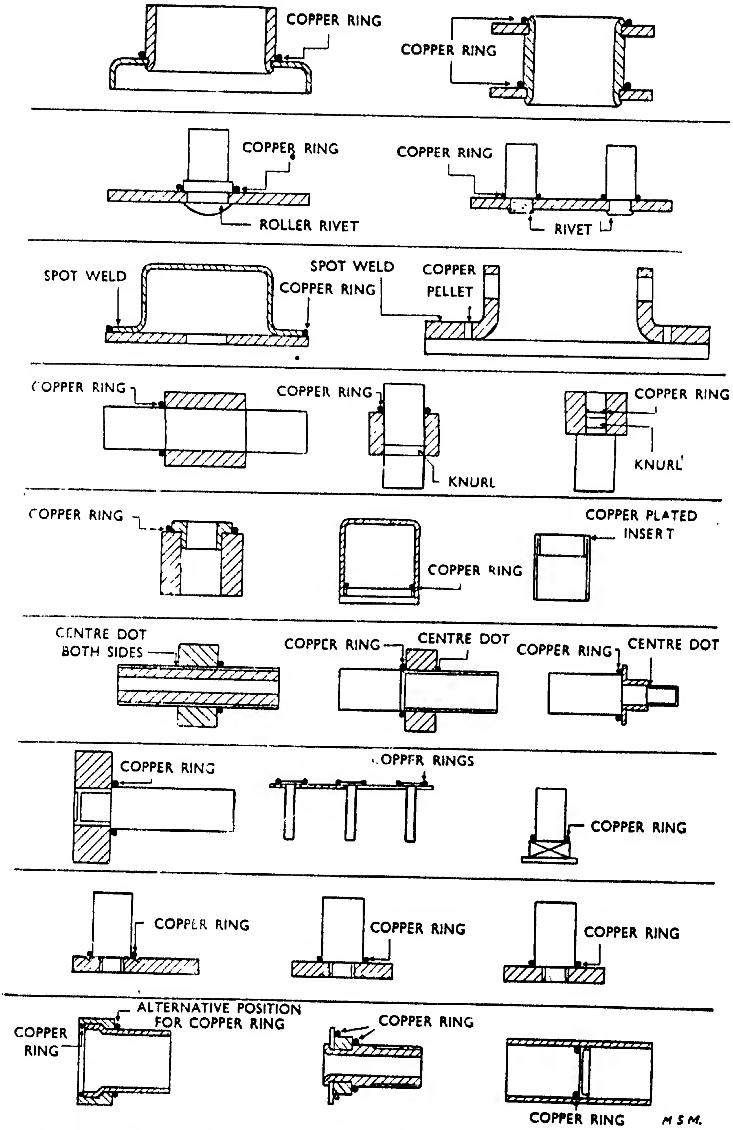


FIG. 3.—SHOWING POSITION LOCATION OF COMPONENTS DURING BRAZING (*Birlec, Ltd.*)

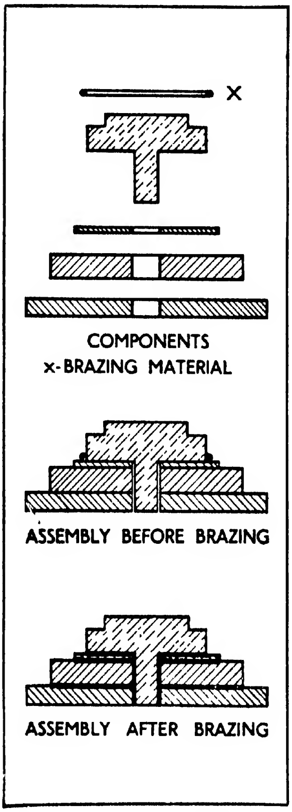


FIG. 4.—A TYPICAL ASSEMBLY OF COMPONENTS. (*Birlec, Ltd.*)

When brazing carbon and alloy steels, the problem of decarburisation is of importance. The type of furnace atmosphere commonly used is strongly decarburising at brazing temperatures to steels having a carbon content of more than about 0·3 per cent. One method of preventing decarburisation is to copper-plate the parts of the component to be protected, but the plating must be evenly applied and non-porous. Alternatively, there is now available a new type of furnace atmosphere which is non-decarburising, even to steels of 1 per cent. carbon content, at copper brazing temperatures of 1,120° C.

The assembled components are conveyed into the heating chamber of the brazing furnace, which is filled with the reducing atmosphere, and when they attain the desired temperature (about 1,110–1,120° C. for copper brazing), the brazing alloy melts, fills the joint, and is kept there by capillary attraction. On completion of this stage in the process, the articles are transferred to an adjoining cooling chamber, also filled with the reducing atmosphere, where they are cooled down before being passed out of the machine.

Automatic temperature control of the furnace is provided, so that all components receive identical treatment, and uniformity of joint is thus assured.

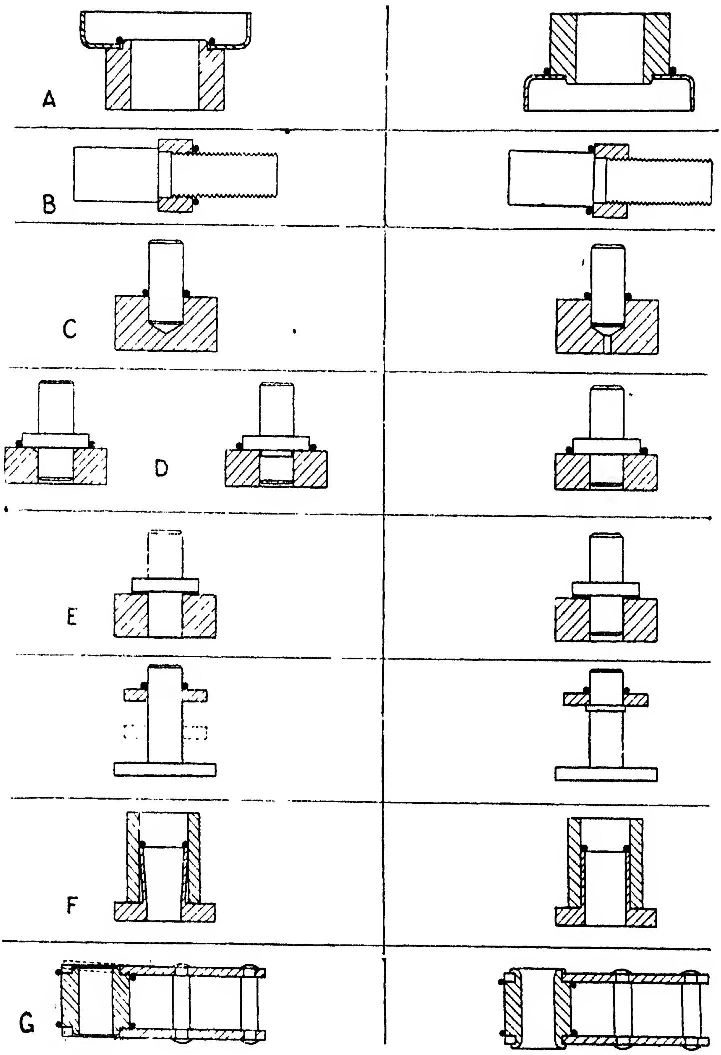
Brazing Furnaces

The most popular type of brazing furnace is the belt-conveyor unit. In this machine, an endless wire-mesh belt, constructed of heat-resisting alloy, passes through the heating and cooling chambers in succession.

Another type is the semi-continuous furnace. This is used for small-scale operations or where the components are too bulky or too heavy to be carried

FIG. 5 (see p. 119).—(*Left*) TYPICAL FAULTY PROCEDURE WHICH PREVENTS GOOD BRAZING. (*Right*) CORRECT PROCEDURE

(*A*) Spigot clearance prevents copper running into joint.
(*B*) Copper tends to run up thread.
(*C*) Expansion of trapped air lifts pin.
(*D*) Chamfer and undercut hinder capillary action.
(*E*) Copper melts to leave gap. Collar will slide down due to differential expansion.
(*F*) Excessive clearance arrests capillary action.
(*G*) Plates warp, due to stress relief.



(*Birlec, Ltd.*)

by a wire-mesh belt. The articles to be furnace brazed are placed in metal trays, which are passed through the heating and cooling chambers of the furnace by a hand or mechanical pusher. With this type, lock chambers at the inlet and outlet ends of the furnace are often provided to minimise the consumption of atmosphere gas.

Where mass production of heavy components is required, a third type, the roller hearth furnace, is used. In this unit, heat-resisting driven rollers replace the conveyor belt. The components to be brazed are put into trays, which are carried by the rollers through the furnace at a predetermined speed.

The atmosphere in the furnace usually consists of a mixture derived from town's gas by partial combustion followed by removal of excess water vapour. Alternatively the atmosphere may consist of cracked or burnt ammonia, but as this is expensive, it is only employed when a high degree of atmosphere purity is essential to the success of the brazing operation.

Properties of Brazed Joints

As already mentioned, furnace-brazed joints have a high tensile strength, and little or no distortion of the component is apparent. In addition, it has even been found that a properly made joint may have a strength higher than that of the parent metal. The reason for this, in the case of brazing mild steel with copper, is that copper-iron alloy is formed in the joint owing to interdiffusion of the mild steel and molten copper.

Strengths of the order 18–20 tons per square inch are readily obtained if the fit of the joint does not exceed 0·002-in. clearance, and figures as high as 24 tons per square inch have sometimes been recorded. With wider clearances the strength falls, and approaches that of annealed copper.

With all metals, the components are in the fully softened condition after brazing, and if they are not of the required strength, they may be submitted to a suitable after heat-treatment, without affecting the brazed joint.

Care should be taken when cyaniding parts after brazing, as prolonged immersion may weaken the joint.

We are indebted to Messrs. Birlec, Ltd., and the Editor of the *Machine Shop Magazine* for the information upon which this article is based.

OXYGEN CUTTING

THE process of cutting iron and steel by oxygen was introduced early in the nineteen-hundreds. Like many other scientific discoveries of this time, its progress as a practical proposition was slow until the advent of World War I. Even then its application was confined to the use of hand cutting blowpipes. The eventual development of oxygen cutting machines dates from about 1921, and from their first inception these machines have made rapid progress in design and performance, so that they are now taking their place alongside other precision machine tools.

The process of oxygen cutting is based on the affinity for oxygen possessed by the iron particles in steel and iron when the material is raised to a temperature of approximately 900° C. Contrary to popular belief, the process is one of oxidation by combustion and not melting. In absorbing the oxygen the iron particles change their chemical form and produce a slag or magnetic oxide (Fe_3O_4). The process, therefore, is one of partial disintegration, the temperatures attained being well below that of the melting-point of steel. In actual practice the velocity of the gases, together with the passage of particles of oxide through the kerf or cut, exercise a scrubbing or scouring effect on the sides of the cut, and quantities of partially oxidised metal are removed in this way. This action, coupled with the low temperatures involved, account for the low thermal effect on metal adjacent to the oxygen-cut face. These factors are also important in the production of accurate, clean profiling and cutting to which we are now becoming accustomed from modern oxygen cutting machines.

Cutting Cast Iron

The oxygen cutting process is, of course, confined to ferrous metals and ferrous alloys, since the metal to be cut must be capable of oxidation at a temperature below its melting-point, and, furthermore, the oxide produced must be fusible at a temperature below the melting-point of the metal. Cast iron, although it does not conform to the foregoing conditions, can be cut, but it requires greater preheating and larger consumption of oxygen than normal steel. Needless to say, it is not possible to cut cast iron with the accuracy or ease with which ordinary steels are cut. Oxygen hand cutters are invariably used for cast-iron cutting, as these equipments are normally designed to give heavier preheat flames and larger volumes and pressures of oxygen than the cutters fitted to oxygen cutting machines. Hand-cutting equipment generally is designed to give a more generous preheat flame than the machine cutter in order to make allowance for the varying speed and inconsistencies of manual

operation. In the case of cutting machines the preheating and cutting flames can be reduced to the minimum because of the stability of the cutter, the constant speed of travel, and the ease with which the cutter height can be controlled. It will be seen, therefore, that in the case of machine profiling, the whole process is more localised and greater precision is obtained.

Hand-cutting Equipment

For general-purpose work, the hand cutter is designed with fine-adjustment valves controlling the fuel gas and the preheat oxygen; the cutting oxygen is usually governed by an "on-off" quick-acting valve. The preheating flames issue through an annulus or a ring of small holes surrounding the central cutting oxygen orifice. The jet and nozzle being made either as two separate items or in one-piece form, this latter design is more common in American equipment. An alternative to these designs is the "step-nozzle" which has made its appearance in recent years. In the step-nozzle the preheat flames issue from a small hole in front of the cutting orifice, which is stepped down so that in operation the nozzle is actually resting on the surface of the work; the velocity of the cutting oxygen stream is sufficient to cause the nozzle to lift slightly during the cutting process. The advantage with this type of equipment is that the preheating flames and the cutting jet are maintained at a reasonably constant height. It is suitable for straight cutting, but is not so efficient for profiling, since the whole equipment must be swung (in the horizontal plane) in order to maintain the preheating flames in front of the cutting jet which it precedes.

OXYGEN CUTTING MACHINES

Generally speaking, oxygen cutting machines fall into two classes, portable and stationary; both types have the advantage of greater precision and economical production over the hand-cutting equipment.

Portable Machines

The two most commonly used portable machines are the straight-line and circle cutting equipments designed for plate-edge preparation and for shaping large plates circular and square. These machines are electrically driven, and can operate equally well on site or in the plate store. Some are fitted with a "floating-head" arrangement, whereby the cutter, or cutters, is constantly maintained at the correct operational height irrespective of the amount of "buckle" in the plate surface. Special equipment is also available on some models to allow oval holes to be cut from a simple template. These machines are also used for machine "gouging" for U- and J-weld preparation. The flame planing machines, which will cut a double V and nose in one operation for weld preparation on medium and heavy plates, are also available, and have played an important part in modern ship construction.

The other type of portable machine is for use in the cutting and preparation of steel pipes and tubes. These are generally hand-driven through suitable

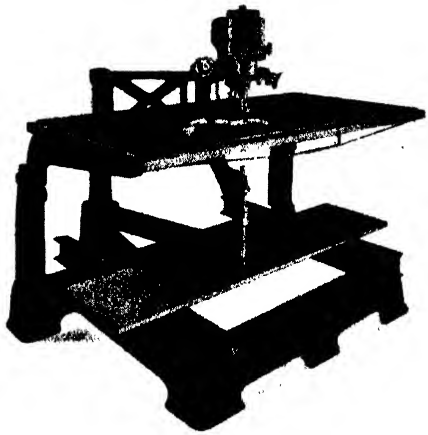


FIG. 1.—TYPICAL UNIVERSAL PROFILER WITH ARTICULATED ARM

All controls are grouped around the tracer head, which can be fitted with alternative forms of drive.

(Hancock & Co. (Engineers), Ltd.)

gearing, which enables the operator to produce extremely clean and accurate work without fatigue. Some of these pipe-cutting equipments are designed for field and site work where simplicity and robustness are the important factors. These machines will cut vertical or bevelled edges up to 45° in either direction, and many are fitted with floating heads to ensure constancy of bevel irrespective of the circularity of the pipe. For pipe work there is also available a special machine with which it is possible to cut holes in the wall of the pipe automatically and without the use of a template. The holes can be either bevelled or vertical, and can be made either on or off the centre line with equal facility.

Stationary Machines

Stationary machine profilers are made in two basic types, the smaller models having the template or tracer head and cutter attached to an articulated or pivoted arm and the larger machines having a compound carriage whereby longitudinal movement is obtained by travel of the main carriage and lateral movement by the motion of a cross carriage mounted upon and at right angles to the main carriage. There are variations of these two main types, but in all cases the compound carriage machines are employed for covering large plate areas and have rather greater accuracy overall than the swinging-arm equipment.

Types of Drive

All machine profilers are electrically driven, and the main difference between various types and makes is in the method of following the template, and the control of the cutting head.

Machines are available in both forms, which have alternative types of drive

RECOMMENDED CUTTING SPEEDS, OXYGEN PRESSURES, OXYGEN AND FUEL-GAS CONSUMPTIONS FOR THE VARIOUS FUEL GASES

		Coal-gas Low Pressure				*Coal-gas High Pressure*				*Propane*				*Acetylene*			
Thickness (in.)	*Jet*	*Oxyge Press. lb. per sq. in.*	*Coal Gas cub. ft. per hr.*	*Oxygen cub. ft. per hr.*	*Speed in. per min.*	*Oxygen Press. lb. per sq. in.*	*Coal Gas cub. ft. per hr.*	*Oxygen cub. ft. per hr.*	*Speed in. per min.*	*Oxygen Press. lb. per sq. in.*	*Propane cub. ft. per hr.*	*Oxygen cub. ft. per hr.*	*Speed in. per min.*	*Oxygen Press. lb. per sq. in.*	*Acety. cub. ft. per hr.*	*Oxygen cub. ft. per hr.*	*Speed in. per min.*
$\frac{1}{8}$	03	25	36	32	16·0	25	50	32	17·0	25	6·0	28	17·0	25	6·6	20	18·0
$\frac{1}{4}$	02	25	40	40	14·0	25	55	40	15·0	25	6·0	34	15·0	25	6·6	23	16·0
$\frac{3}{8}$	01	30	46	68	12·0	30	52	53	13·0	30	6·6	48	13·0	30	7·4	39	15·0
$\frac{1}{2}$	1	33	47	82	12·0	33	59	75	13·0	30	6·6	66	13·0	30	7·6	48	14·0
$\frac{3}{4}$	2	35	48	111	11·0	35	60	105	12·0	34	7·4	87	12·0	34	8·4	74	13·0
1	2	40	52	119	10·0	40	70	115	10·5	40	7·6	105	10·5	40	10·4	88	11·0
$1\frac{1}{4}$	3	45	56	162	10·0	45	74	151	10·5	45	7·8	135	10·5	45	12·4	119	10·5
$1\frac{1}{2}$	3	50	60	178	9·0	50	76	168	9·5	50	8·0	146	10·0	50	12·4	135	10·0
2	4	55	64	237	9·0	55	78	210	9·5	55	8·2	204	9·5	55	12·6	183	10·0
$2\frac{1}{2}$	4	60	66	258	8·0	60	80	228	8·5	60	8·4	214	8·5	60	14·4	200	9·0
3	5	65	69	300	7·0	65	86	282	7·5	65	8·6	265	7·5	65	14·8	256	8·0
4	5	80	84	413	6·0	77	92	394	6·5	78	8·8	370	6·0	77	15·8	330	6·5
5	6	85	90	440	6·0	85	96	420	6·5	84	9·0	390	6·0	83	18·0	378	6·5
6	6	95	92	480	5·5	95	98	462	6·0	93	11·0	420	5·5	90	20·0	410	6·0
8	7	105	94	750	5·0	105	130	715	5·25	105	18·0	710	5·5	103	25·0	700	6·0

(*Hancock & Co.* (*Engineers*), *Ltd.*)

Note.—The above figures are given as a guide for cutting mild steel. They may be varied slightly according to the size, quality, and surface condition of the steel being cut.

or template following devices; thus it is possible to obtain profiles from templates made from plywood, aluminium strip, or steel templates. One manufacturer offers a drive whereby it is possible to make the cut from a full-sized drawing. This is particularly attractive where only off jobs are required, and where the cost of a complicated or costly template is not warranted. This same machine, nevertheless, can be fitted with alternative drives permitting wood, metal strip or steel templates to be used where production runs are contemplated.

Articulated-arm Machines

Articulated-arm machines are available in various sizes, and are suitable for the average run of profiled work. They cannot, however, be used for bevelling work, except in such cases where the material can be tilted to give the necessary angle to the cutting nozzle. The compound carriage-type machines are invariably fitted with bevel-head cutters, enabling bevels to be cut longitudinally or transversely as the case may be.

Multi-burner Machines

For mass-production profiled work, multi-burner machines are made which enable three, four, five or six off to be cut simultaneously from one template. The degree of skill necessary for working such machines is surprisingly small, since the cutters are controlled from a single lever control and the template is usually of the automatic magnetic or twin-roller type.

In the normal way, cutting machines will handle all material from $\frac{1}{8}$ in. to 16 in. thickness, the only adjustments being the nozzle and jet sizes, the oxygen pressures and cutting speeds (see page 124). The manufacturers supply charts which enable the operator to select the correct procedure for any type or thickness of material.

The tendency nowadays is towards greater accuracy in profiling and shaping, since modern methods of welding, particularly the semi-automatic types of arc welding, call for greater accuracy in set-up of components to be welded. Working tolerances as close as 0·005 in. have been obtained with oxygen cutting, but the normal run of fine tolerance work is usually $\pm$ 0·010 in. or $\pm$ 0·020 in. To obtain these fine limits, the machine has to be maintained in the same way as a normal machine tool, whilst the operator has to be fully experienced and diligent in his work. In the less accurate work, tolerances of $\pm \frac{1}{32}$ in. in thickness up to about 1 in. are easily obtained by an experienced operator.

Template following by "Electric Eye"

A recently introduced machine employs the "electric eye" for guiding the machine from a paper drawing, and extremely fine limits are claimed for this method of template following which, for some classes of work, offers extreme accuracy with great economy by the elimination of templates. This machine works on the principle of the photo-electric cell, which follows a spot of light

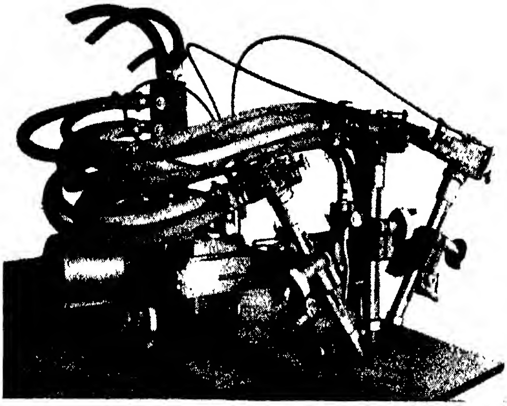


FIG. 2.— PORTABLE FLAME PLANING MACHINE FOR PLATE-EDGE PREPARATION

The three burners are attached to a floating-head device which maintains the cutter at a constant height above the work. (*Hancock & Co. (Engineers), Ltd.*)

projected on to the profile drawing. Electric circuits from the cell are coupled to the steering and travel motors of the machine in such a way that the spot of light follows the outline of the drawing and reproduces the profile in steel of practically any thickness. This British development will undoubtedly attract users of the process who have to deal with large and complicated shapes, such as are met with in the construction of locomotives, mechanical handling, and earth-moving equipments, etc. It also has a valuable application in shipbuilding.

Profiling Stainless Steel

Yet another recent development to oxygen cutting equipment is that of profiling stainless steel. Three methods are at present being employed for this most important work. Firstly, there is the oxy-arc process, employing a hollow electrode connected to a normal arc welding plant. The arc is struck between the end of the electrode and the work in the usual way, and oxygen is then fed down the central bore of the electrode. The electrode burns away, of course, but the presence of a large volume of oxygen at the arc point enables a quick reaction to be built up and maintained with the stainless steel. The cut so made corresponds to the cut in mild steel made with a hand cutter and inferior to a machine cut. The process, nevertheless, has many useful applications in the handling of stainless steel and other alloys. The other two methods of profiling stainless steel are based on the introduction of a powder into the cutting stream. In one case the powder is in the form of "iron powder," which readily reacts with the preheated metal and the oxygen cutting stream. The alternative process employs a non-metallic powder or flux which is carried in the cutting stream. The first is known as the "powder-injection system" and the second as the "flux-injection process." The latter process employs a special flux which reacts with the chrome-oxides created by the application of the oxy-acetylene flames and the cutting oxygen. This process has been proved very satisfactory

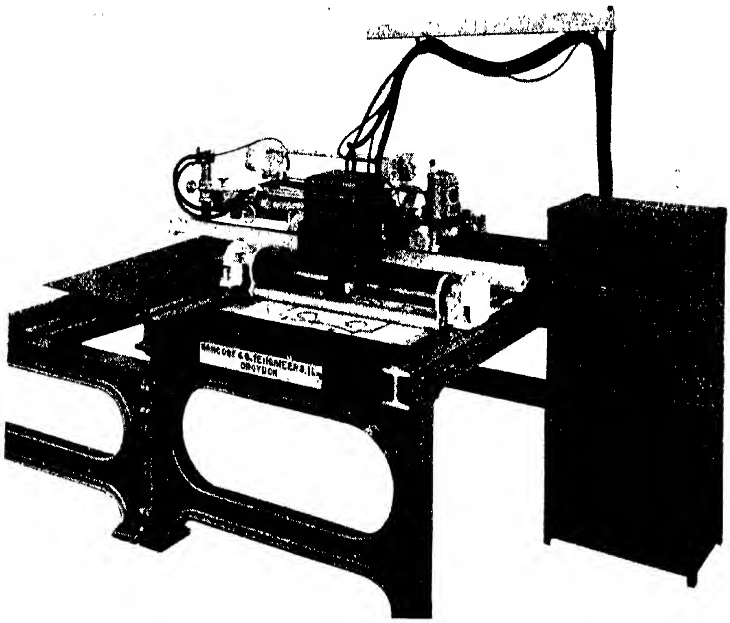


FIG. 3 —LARGE-AREA PRECISION PROFILER FITTED WITH ELECTRONICALLY CONTROLLED TRACER HEAD

A photo-electric cell follows a spot of light projected on to the drawing automatically, ensuring a high degree of accuracy between the drawing and the work. (*Hancock & Co. (Engineers), Ltd.*)

for the profiling and cutting of stainless steel for chemical and food vessels. The stainless qualities of the material are not impaired in any way by the process. Both powder- and flux-injection processes have the advantage that they can be adapted to existing profiling machines without undue modification. As might be expected, considerable heat is necessary in the cutting of stainless steel, and both processes employ acetylene as the fuel gas. The speed of cutting stainless steel varies only slightly from that of cutting mild steel in the normal way; the iron powder method is probably the faster of the processes, and is more applicable to thicker sections of material.

Fuel Gases

Modern oxygen cutting machines can be adapted to work from almost any inflammable fuel gas. The three most common fuel gases are acetylene, propane, and coal gas. Coal gas is employed direct from the supply main, and does not require boosting or regulating for normal work, provided that it has a calorific

value of 450 and is supplied at a pressure above 4 in. water gauge. Oxy-coal gas is extremely suitable for profiling and cutting, since the temperature of the preheat flames obtained is comparatively low, and it is practically impossible to overheat the work during the cutting process. Clean cuts are easily obtained, having a sharp, square top edge with minimum thermal effect on the metal adjacent to the cut face. For thicknesses exceeding say 10 in., it is usually necessary to boost or enrich coal gas in order to raise the heat input value.

Oxy-propane is finding increasing favour with profiling and cutting operators. It has a higher rate of heat input than coal gas, but is not so critical in use as acetylene. It gives a good stable flame, and is therefore easy to work with. It is particularly suitable for site work, where portability of equipment is often of prime importance. Propane is a so-called liquid gas, and is obtainable in cylinders containing 28 lb. and 60 lb. weight. One pound of propane gives approximately 9·8 cub. ft. of gas.

Acetylene is the "hottest" fuel gas, i.e. it has a high calorific value, with a correspondingly high rate of heat-input. When used as a fuel gas for oxygen cutting, it gives an intense flame enabling quick starting to be made. It is fairly critical in use, especially on the medium thicknesses; but its main advantage, so far as the process is concerned, is that its high rate of heat input makes it most suitable for heavy cutting. Acetylene is obtainable either in "dissolved" form in cylinders or from medium- or low-pressure generators. There is little or no difference in working with either form of this gas; the generated acetylene offers greater economies from the point of view of gas cost.

Thickness of Material

There is practically no limit to the thickness of material which can be cut with the oxygen cutting process. Such limits as there are are provided by physical restrictions imposed by the requirement of large volumes of oxygen and attendant preheating facilities. Thicknesses up to 72 in. have been successfully cut, and doubtless this figure will be exceeded in course of time. In thick cutting there has been an important development in the use of large-bore jets using low-velocity oxygen, and this appears to have many advantages both in accuracy and economy on thick materials.

Operational Costs

The cost of oxygen cutting varies according to local conditions, etc.; but some idea of the cost in materials (fuel gas and oxygen) may be gathered from the cost of cutting 1-in. thick plate at the present time. Depending upon the type of fuel gas used, this may vary from 1*d.* to 1¼*d.* per foot run, and since this thickness can be cut at approximately 1 ft. per minute, the total cost, including labour, may easily be judged.

Whilst comparatively little skill is required to effect good-quality cutting, where maximum accuracy is required, some form of supervision is necessary, especially where operators are working piece-work rates. Apart from the cost

of labour, the consumption of oxygen is the prime factor in economy, and inefficient operation can prove costly in this otherwise economical process.

OPERATING NOTES FOR OXYGEN CUTTING MACHINES

Modern oxygen cutting machines are made as automatic as possible, but owing to the varying types of steel, a certain amount of latitude is available in setting the correct flame adjustment. Incorrect operation in flame setting gives a characteristic blemish or deformation to the cut face.

For example: if an excessively heavy preheat flame is set, the resultant cut will show a heavy roll or radius to the top edge of the cut. Similarly, if too high a pressure of cutting oxygen is used, the lower edge of the cut will carry a heavy accumulation of oxide. Other easily recognisable signs of incorrect operation are as follows: nozzle too high above work—the cut will be chamfered; nozzle too low—cut will be distorted and will have possible under-cut near the top edge; speed of travel too fast—the characteristic "drag-lines" will show a backward sweep, together with deformation of the cut face; cutting oxygen pressure too low—cut face will be square, but the oxide may "reweld" itself at the bottom of the cut, preventing the workpiece from being separated from the parent metal. Too slow a speed of travel may have a similar result, but in this case the top edge of the cut will show a bead effect and the cut face will probably not be square.

The most common operational faults are: excessive preheating and excessive cutting oxygen pressure, both of which give deformed cut faces. The manufacturers' advice on optimum cutting pressures should be closely followed; an increase in pressure of only 10 per cent. can give rise to an increase in consumption of oxygen amounting to over 80 per cent.

A correctly made cut on normal mild steel will appear clean, square at both top and bottom edges, and will require no cleaning or fettling save for the removal of the flakes of oxide, which should fall away when lightly tapped or brushed. Dirty plate, or plate having a heavy mill scale, may require cleaning with a wire brush before cutting operation commences. Mill scale can be easily "cracked-off" by passing the preheating flame over the line to be cut and wire brushing afterwards. Such practice is worth while, as it eliminates the possibility of particles of scale falling into the kerf as the cut proceeds.

Machines are available which have a flame preset device incorporated in the cutter control that eliminates any hazard of obtaining identical flame settings for repetition work. With this control, once the correct flame setting has been found, the operator can obtain absolute consistency throughout a complete run of profiled shapes.

Apart from the advantage of template accuracy, the modern oxygen cutting machine will reproduce quite intricate shapes with greater speed and accuracy and at less cost than any other mechanical shaper or cutter. This is particularly true when dealing with thicknesses of ¼ in. and over.

E. S. S.

SHIPYARD WELDING

PREVIOUS articles have dealt with the various aspects of arc-welding technique and equipment such as is encountered in general engineering practice, and this article reviews the use of welding in the shipbuilding industry, and its influence on the design of vessels, manufacturing methods, and the layout of the yards.

Possibly the most important development in the shipbuilding industry during the last decade has been the ever-increasing use of welded construction. However, although the first all-welded British vessel was built in 1918, complete replacement of riveting by welding has progressed very slowly, and, in this country, has not yet been adopted for large vessels. In the past, there has been considerable prejudice in the shipbuilding industry against the large-scale use of welding, although this has now been largely overcome as the result of experience gained with the all-welded Liberty ships and other smaller vessels built during the late war.

The extent to which welding is employed is gradually increasing, and at the present time is in the region of 75–80 per cent. for large vessels, although all-welded construction is now quite common for smaller types. This means that 75–80 per cent. of the structure is assembled by welding, the remainder being riveted. It is universally acknowledged that a correctly made weld is as strong as the parent metal, a statement that has been borne out by examination of welded vessels which have been involved in mishaps. Only in very isolated cases has weld failure occurred, and even then the same failure would no doubt have taken place if the seam had been riveted. In practically every instance the weld was intact, although adjacent parent metal was torn apart. In fairness, it should be pointed out that much of the objection to welded construction came from the owners, i.e. the persons for whom the ship is built, and who, naturally, specify the type of construction to be adopted.

In order to make a successful job it is essential, when designing the vessel, to design it for assembly by welding, and not merely to weld together parts originally designed for riveting, but this is a separate and lengthy subject which cannot be dealt with here. One point may be mentioned, however, i.e. local concentrations of rivets at butts, three-ply connections, and straps should always be replaced by welds.

Advantages of Welded Construction

Apart from technical considerations, certain important advantages are possible from the adoption of welded construction. Of these, the most important

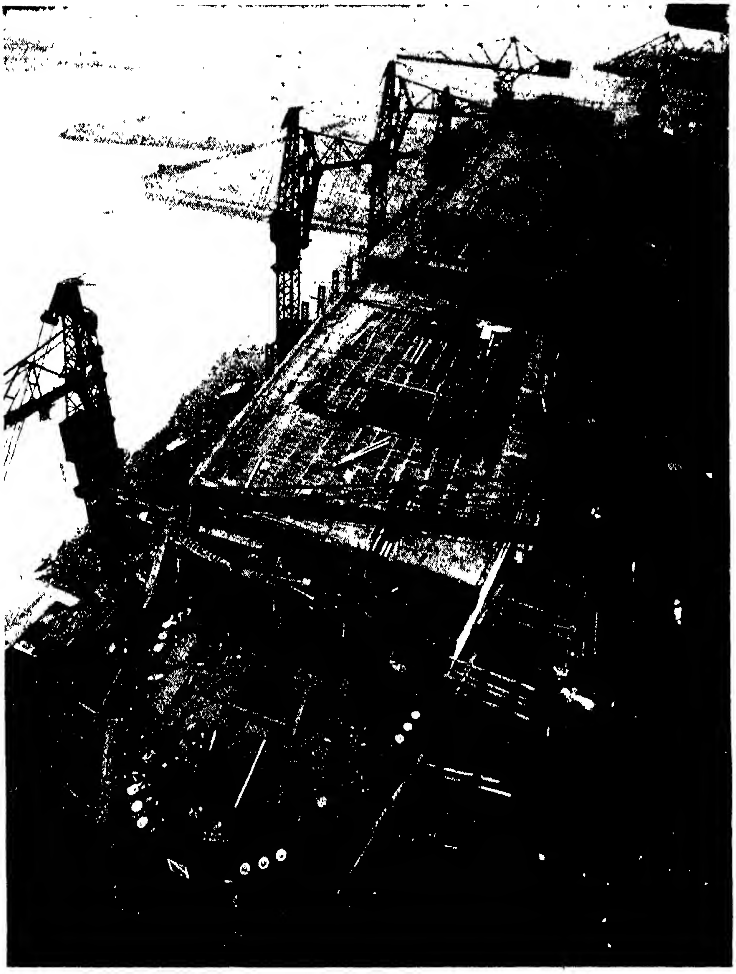


FIG. 1.—OVERHEAD VIEW OF A CUNARD WHITE STAR LINER, SHOWING SUPERSTRUCTURE COMPLETED (*Cunard White Star, Ltd.*)

are: (1) prefabrication, (2) economy of material, weight, and labour, and (3) quickness. With regard to material and weight economy, this arises largely from the elimination of the need for overlapping plate edges to accommodate the

rivets. It has been estimated that in a 10,000-ton vessel, the saving is in the region of 200 tons. Considerable weight saving is also effected by the replacement of large steel castings, weighing often 100–300 tons, by welded structures weighing only a fraction of these figures. The elimination of marking-out, drilling, de-burring, and caulking the holes is also responsible for considerable labour and time saving, as well as the fact that, in most cases, welding is cheaper and quicker than riveting.

The most important change arising from the large-scale use of welding is the much-extended employment of prefabrication, which is now one of the major features of welded construction. Although this technique was, and still is, used also for the construction of riveted vessels, it has proved particularly suitable for welded work.

Prefabrication consists of constructing large portions of the vessel as units, which are joined together at the building berth. Considerable time and labour economies are possible by this method, particularly as much of the work can be done under cover in shops away from the berth. The manner in which this is applied in present-day yards will be seen from actual examples given later. The size of the units is governed largely by the crane capacity, and generally ranges up to approximately 12 tons.

Yard Layout

To make the most efficient use of welding, it is essential to lay out the yards in a special manner. In the past, the yards were arranged to handle riveted work, and one of the contributory factors to the slowness in adopting welded procedure has been the delay caused by completely rebuilding and rearranging the present yards. Huge sums have been spent on re-equipping British shipyards for welding, and much of the work is now nearing completion. When considering the various layouts given later, it must be remembered that most shipyards are hemmed in by buildings and rivers, and cannot be expanded or the shape altered to permit the most theoretically correct layout.

Line-flow production is the ideal aimed at in all cases, i.e. forward movement of all stages towards the building berth, so that the prefabricated units end up close to the point at which they are to be used. If space and site conditions permitted, the yard layout would be similar to that in Fig. 2 (*a*).

Here, from the open-air plate park, the plates are transferred by crane to a large covered plate shop of considerable height and well equipped with cranes. As they enter, the plates are straightened in plate mangles, and then pass on for marking off. In the adjacent section they are cut to size and shape with guillotines or oxy-acetylene equipment, and then move on for plate-edge preparation, unless this operation was performed simultaneously with cutting to shape.

The smaller units are fabricated in the next section, large work being assembled in the open. Even in the latter case, it is generally possible to weld much of the work under cover before transference outside. Part of the welding shop is generally equipped with "skids," comprising a series of rails, mounted approximately 3–5 ft. above ground level. Work which requires welding on both

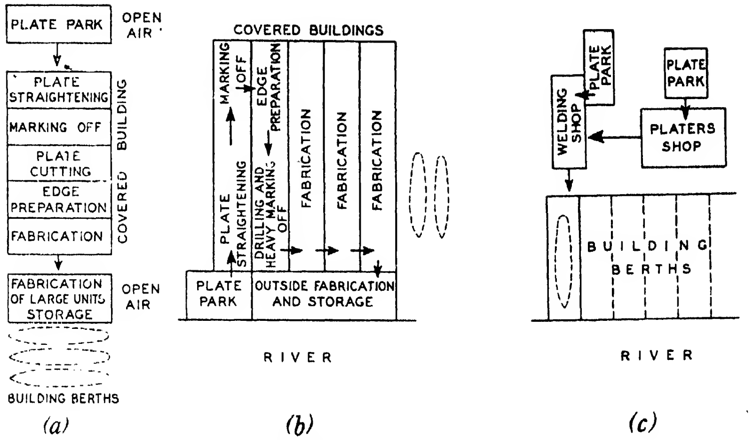


FIG. 2.—THREE SHIPYARD LAYOUTS

(*a*) Representing the theoretical ideal, and (*b*) and (*c*) the layouts actually employed in two British yards.

sides can be performed with ease by welders working above and below. Also, in some cases it facilitates the use of downhand procedure when it would otherwise be difficult to achieve.

Both large and small units are then stored in a position where they can be reached by a crane system feeding the building berths. In the layouts shown in Fig. 2 (*b*) and (*c*), it will be observed that this principle has been followed as far as possible.

Edge Preparation

Most plate-edge preparation is done by flame cutting, i.e. oxy-acetylene torch, this operation usually being combined with cutting the plates to size and shape. Alternatively, long straight edges are sometimes cut by guillotine—the edges being left untrimmed—or by planing. Wherever possible, flame cutting is performed automatically, the torch or jet being fed along the plate by mechanical means.

The type of preparation to be used for a plate of specified thickness varies slightly from yard to yard, but the following figures provide a useful average. Plates up to $\frac{1}{4}$-in. thick are left with a square edge, and thicker plates up to $\frac{5}{8}$-in. thick are provided with a single $\frac{3}{32}$-in. chamfer on the underside. Above this thickness, double V preparation is employed, the depth on one side being equal to one-third of the plate thickness and two-thirds on the other. In most yards the welding technique is standardised, and charts are issued to the operators specifying such data as the welding position, number of runs, electrode gauge, welding current, and deposit for every condition likely to be encountered. By this means, chances of incorrect welds are considerably reduced.

FIG. 3.—MANUAL ARC WELDING IN OPERATION

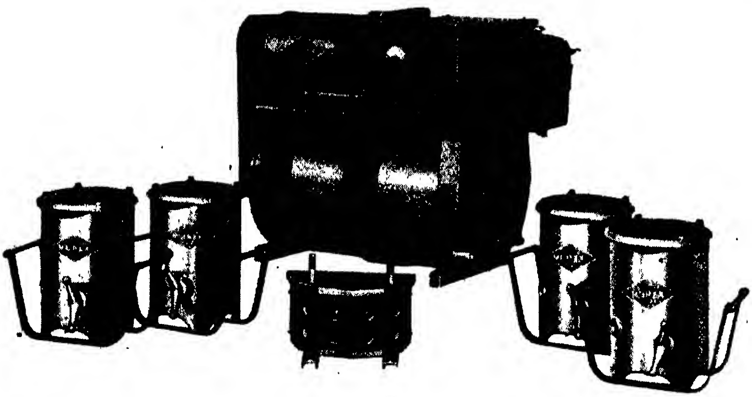


FIG. 4.—MULTI-OPERATOR ARC-WELDING EQUIPMENT

This is a 150-cycle motor alternator arc-welding equipment providing four operators with a welding current of up to 300 amps. each. The use of the 150-cycle frequency makes the arc easier to control, giving speedier welding and better penetration. (*Murex Welding Processes, Ltd.*)

WELDING EQUIPMENT

Two main types of equipment are used for shipyard work, i.e. manual and automatic, the latter being reserved for long, straight welds, such as are encountered when joining deck plates, assembling tank sides, floors, and tops, and for various other seams and butts. As a general rule, wherever possible all heavy downhand straight runs are done by machines, manual welding being reserved for light fillet work or for jobs which have to be done vertically or overhead.

Electrical Supply

Some British yards employ A.C. welding, whilst others favour D.C. For example, one large firm use A.C. for all hand-welding in the shops, and D.C. on the building berths. Approximately 20 per cent. by volume of their total welding is done with automatic machines. this high figure demonstrating the extensive use made of this type of equipment.

In another yard, current for welding is supplied by eight generators ranging from 4,000 amps. to 5,000 amps. capacity. Connected to the lines leading from the generators are portable resistance boxes, which are moved to suit the location of the work. These reduce the generator station supply to 300 amps., but can be connected in series to give higher values. Each box incorporates switches enabling the current to be varied in 20-amp. steps from a minimum of 20 amps., thus providing fine adjustment to suit practically any working condition. In addition, there are several self-contained portable welding sets, one being of 2,500-amp. capacity and capable of supplying 25 operators. There are also two

FIG. 5.—AUTOMATIC WELDING OF DECK PLATING WITH UNIONMELT MACHINE
See page 26 for description of the Unionmelt process. (*The British Oxygen Co., Ltd.*)

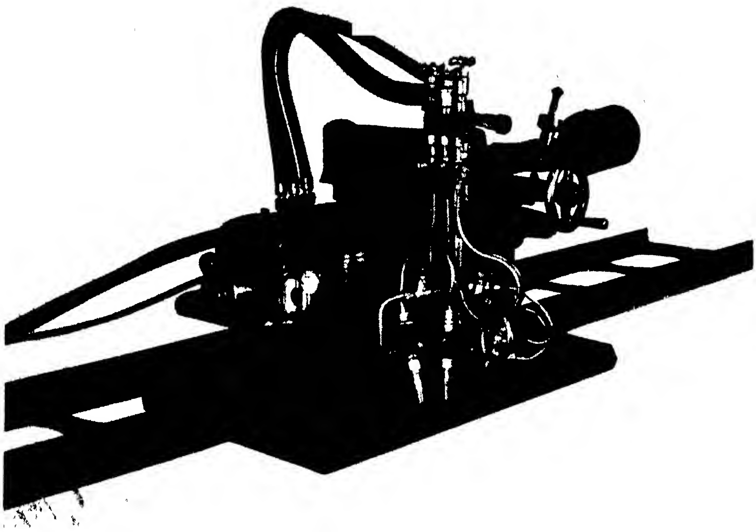


FIG. 6.—AUTOMATIC CUTTING AND DOUBLE BEVELLING MACHINE
(*The British Oxygen Co., Ltd.*)

800-amp. sets and a number of single-operator units. All the equipment in this particular yard is arranged for D.C.

In a third yard, standard A.C. equipment is used throughout, the bulk of the power being taken from the grid system at 11,000 volt 3-phase and stepped down to 400 volts at the substation. Throughout the prefabrication shops it is distributed by eight transformers, each capable of accommodating 70–80 welders. In the building berths there are six transformers, each supplying 50–60 operators. Also, in addition to the ordinary welding equipment, there are three automatic welding machines. To balance the load, one machine is arranged on each phase.

After careful investigation, a fourth firm decided that the cost of maintenance of A.C. sets was approximately 75 per cent. less than for D.C. sets. As a result, apart from a few sets reserved for stud welding and for welding non-ferrous metals, their yards are now equipped throughout for A.C. work. This particular firm has two yards; in the South yard seven 500-kVA, 3,300/440-volt power transformers supply the welding installations, while in the North yard the plant includes four 165-kW motor generator sets (3,300-volt synchronous induction motor drive and 100-volt D.C. generators) and one 100-kW motor generator set comprising a 3,300-volt motor and a D.C. generator supplying the welding current.

For A.C. welding in the North yard, the equipment comprises 440/173–100-

volt, 180-kVA and 153-kVA arc-welding transformers distributed throughout the slipways and welding bays. The power supply is through a 1,000-kVA 3,300/440-volt power transformer situated in the main power station. After stepping down to 440 volts, the current is then brought down to 100 volts by means of individual arc-welding transformers.

SHIPBUILDING

The following examples provide a useful guide to the way in which welded ships are actually constructed in British yards.

Prefabricated Barges

An interesting case is provided by a 130-ft. all-welded oil barge, which has a weight of 200 gross tons. It is of straightforward design (Fig. 7), comprising three oil tanks divided by a central longitudinal bulkhead: the engine room is

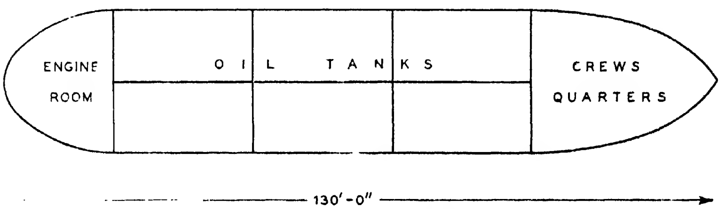


FIG. 7.—SHOWING HOW THE ALL-WELDED OIL BARGE IS SPLIT INTO UNITS FOR PREFABRICATION

aft and the crew accommodation forward. Because of its small size, this vessel is almost completely prefabricated in the shops, the units being welded together in the building berths. For this purpose it is divided into bow and stern sections, and a midship portion divided into four 21-ft. lengths; the bottom, sides, bulkheads, and decks of the latter unit are constructed as prefabricated units.

The sequence of building is as follows: first, the four bottom panels for the midship portion are laid down, and the bulkheads and sides erected in position. After this, the deck panels are attached, forming a box-like structure which is tack-welded, faired, and then finish-welded. To this are welded the previously prefabricated bow and stern units.

Welded-riveted Construction

Some of the larger vessels are of combined welded-riveted construction. In such cases, the large flat portions are generally welded. These include such items as the deck seams and butts, transversal and longitudinal bulkheads, and tank tops. These units are prefabricated in the shops, and then welded in position at the berths.

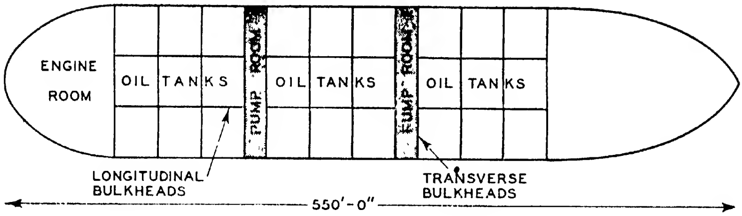


FIG. 8.—GENERAL DESIGN FOR LARGE TANKERS

Oil-tanker Construction

The following description concerns the building of an oil tanker capable of carrying a cargo of 16,000 tons. The ship (Fig. 8) is 550 ft. long by 70 ft. wide, and comprises nine sets of main tanks subdivided into three compartments transversely by two longitudinal bulkheads. These are further subdivided into three sections by two cargo pump rooms. From this it will be seen that much of the interior comprises large flat bulkheads, which are ideal for prefabrication.

The method employed in this yard for building all-welded tankers is first to lay out and then completely weld the bottom of the keel and flat of bottom shell, following this by adding the oil-tank bulkheads.

Each bulkhead (Fig. 9) consists of three 8-ft. wide by 32-ft. long vertical panels welded to a 7-ft. by 24-ft. wide horizontal baseplate; the panels are $\frac{1}{2}$ in. thick and the baseplate $\frac{7}{16}$ in. thick. Welded on the outboard side are a series of vertical stiffeners and three horizontal stringers. When prefabricating the bulkheads the panels are laid loosely on channels, the first step consisting of welding together the three vertical plates and then adding the baseplate. Finally, the stiffeners and stringers complete the unit.

The bulkhead is then slung vertically into position by crane, welded to the

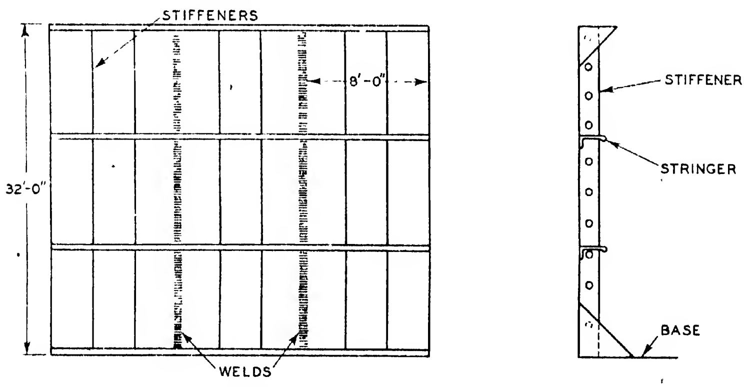


FIG. 9.—DESIGN OF PREFABRICATED WELDED TANKER BULKHEADS

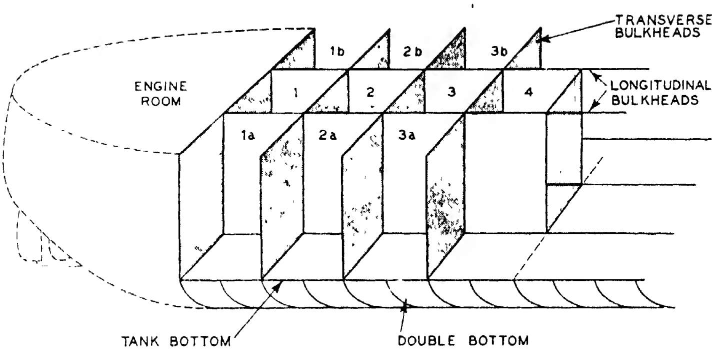


FIG. 10.—EARLY STAGES IN THE BUILDING OF AN OIL TANKER

bottom, and then supported in position by suitable overhead tackle. Following this, the longitudinal bulkhead for the opposite side is prepared in a similar manner and stood temporarily in a vertical position facing the first bulkhead. The transverse bulkhead is then raised in position, and the three units welded together. This procedure is followed for all tanks (Fig. 10). In this particular yard, work commences aft of the ship, working forward until the tanks are complete.

When all the bulkheads are complete, the deck is added, this being followed by the shell, starting amidship approximately half-way up the shell side and working up and down, and outwards to the ends of the vessel. The final stages consist of adding the bridge and other items of the upper structure.

All the seams and butts of the tank top, bulkheads, and bottom shell and decks are welded with automatic equipment. Automatic welding is also employed for the seams and butts of the masts, derrick posts, and pillars, and also for fillet welding many of the prefabricated sections.

Replacement of Castings

The structural design of every ship necessitates the employment of a number of very large and heavy castings which, on larger vessels, weigh up to several hundred tons. These are now often replaced by fabricated structures built up from plate by welding. By this means the weight is considerably reduced without sacrifice of strength, costs are much lower, and delivery is speeded up. In some designs, castings and welded fabrication are blended together, a typical example of this being provided by the rudder. Very large castings are required also in the engine room, particularly for engine beds. It is now quite common practice to replace these heavy and expensive steel castings by fabricated units welded in sections in the workshop, and then lowered into the engine room and joined together to form a single unit.

J. A. O.

WELDING AUTOMOBILE BODIES

APART from very minor operations, the modern all-steel automobile body is assembled exclusively by one form or another of welding, this applying also to the chassis. Some idea of the amount of welding performed in the British Isles may be gauged from the fact that the output from one leading manufacturer alone exceeds 126,000 vehicles per year.

Because welding plays such an important part in automobile manufacture, special attention has been paid to allied branches of the subject, such as designing the body to suit welding, the layout of production lines to make the best use of welding, the design of welding fixtures, and the design of welding equipment. In the following review of the use of welding for automobile body assembly purposes it must be remembered that methods differ slightly from firm to firm, according to the opinions of those responsible for planning. The same broad principles, however, apply throughout the whole industry.

Influence of Costs

In automobile manufacture, production costs have been given considerable attention. Although minute sums may seem unimportant for a single car, the accumulative figure over a year is considerable. Thus, one of the essentials of car-body manufacture is cheapness. Assuming that materials and methods for shaping the parts are at their most economical level, cheapness means largely the quickest possible method of assembly compatible with good workmanship. In passing, it may be mentioned that most of the work is done with spot-welding equipment, although limited use is made of gas welding and certain of the other electric processes.

Preliminary Stages

The preliminary procedure for the production of a new car body is as follows. Knowing the type of body required, the h.p. of the engine, the wheelbase, and the track, a $\frac{1}{8}$-in. or $\frac{1}{4}$-in. scale drawing is made. From this, models are made in wood or plasticine, these being painted in the proposed colours. Sometimes as many as a dozen models are made before the main contours are finally approved. The next stage is the production of full-size layout drawings which, to avoid the effects of contraction or expansion arising from changes in climatic conditions, are sometimes made on hydraulically stretched aluminium sheets.

Conferences are then held between the Design and Production Departments,

the latter often desiring modifications in order to simplify production, reduce manufacturing costs, or make a neater job. Having agreed on the general contours, the body is then split into sections suitable for production.

PLANNING PRODUCTION

As far as welding is concerned, the next stage is to produce subassembly sketches showing the extent and position of the welds. These are drawn in the manner shown in Figs. 2 and 3. The various sections are marked and numbered on this "key" pictorial drawing, which allows the subassembly drawings to be easily identified. As there will be a considerable number of such drawings for each different body, some simple method of identification is essential in order to avoid confusion.

From the subassembly drawings it is then possible to determine technical details regarding the welding equipment necessary for each subassembly and the position and number of welds to be made. This stage is followed by the planning of the actual sequence of operations. This is of considerable importance if costs are to be kept to a minimum. For example, if the units are assembled in the wrong sequence, it may be found that some parts are hidden by previously welded units, and are either completely inaccessible or very difficult to reach. It may even be necessary to design special guns or electrodes to overcome some of the snags. Again, the choice of a faulty assembly sequence may mean that certain parts have to be handled more often than absolutely necessary.

The plan generally adopted is to split the body into several major subassemblies which are made on self-contained lines or sections situated close to the main assembly line where they are to be welded together to form the body.

Shop Layout

The next step is to plan the layout of the shop, which to a large extent is governed by the size and shape of the floor space available. Sometimes a straight main assembly line fed by straight subassembly lines is possible, this ideal layout, unfortunately, requiring considerable floor space. In other cases, the main assembly line may be in the shape of an oval, with the subassembly sections grouped either inside or outside the line, or both. Again, the space available may perhaps be best utilised by such means as shown in Fig. 10. In every instance, the ideal to be aimed at is to install the maximum amount of equipment in the smallest possible space. Each time another model is put into production it is necessary completely to strip the floor of all conveyors and equipment used for the previous model and then replan it to suit the new conditions. Suitable provision must be made for storing the work, and this must be arranged so as not to impede the movement of either operators or material.

Whilst the floor space available governs to a large extent the shape of the production lines, another extremely important factor is the output of bodies required from the department. In fact, this is the datum figure for many important calculations. For example, it governs the speed of the main assembly

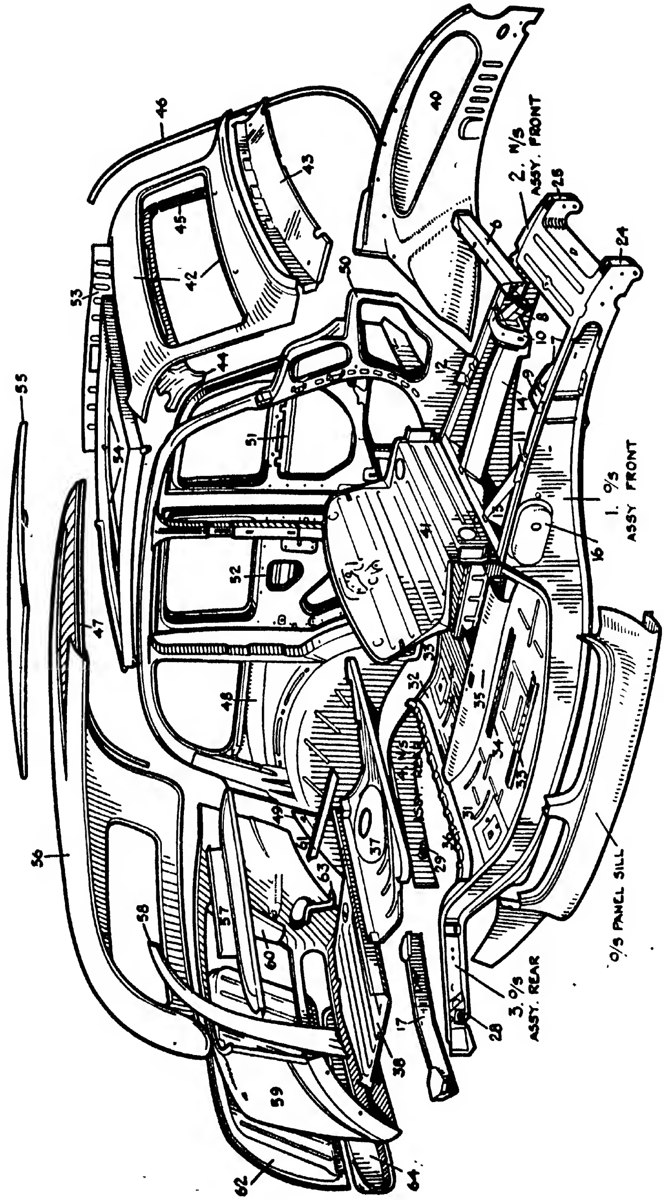


FIG. 1.—DIAGRAM OF A TYPICAL AUTOMOBILE-BODY OUTER SHELL, WITH THE VARIOUS SUB-ASSEMBLIES NAMED
It should be noted that the nomenclature adopted by various firms often differs slightly. (*The Nuffield Organisation*)

KEY TO FIG. 1.

1. Side-member assembly (front) O/S
2. Side-member assembly (front) N/S
3. Side-member assembly (rear) O/S
4. Side-member assembly (rear) N/S
5. Front splasher assembly
6. Front cross-member assembly
7. Stiffener (front cross member to engine bracket) O/S
8. Stiffener (front cross member to engine bracket) N/S
9. Front engine-bracket assembly O/S
10. Front engine-bracket assembly N/S
11. Stiffener (front shock absorber) O/S
12. Stiffener (front shock absorber) N/S
13. Frame brace assembly O/S
14. Frame brace assembly N/S
15. Dash support cross-member assembly
16. Spacer (chassis to valance)
17. Rear cross-member assembly
18. Stiffener assembly (main floor) O/S
19. Stiffener assembly (main floor) N/S
20. Floor cross-member assembly (front) O/S
21. Floor cross-member assembly (front) N/S
22. Clutch-pedal bracket assembly
23. Tunnel assembly (lower)
24. Front-spring front-bracket assembly O/S
25. Front-spring front-bracket assembly N/S
26. Front-spring rear-bracket assembly
27. Rear-spring front-bracket assembly N/S
28. Rear-spring rear-bracket assembly O/S
29. Rear-spring rear-bracket assembly N/S
30. Front floor-panel assembly
31. Floor side assembly O/S
32. Floor side assembly N/S
33. Seat runner (locking)
34. Seat runner (plain)
35. Tunnel assembly (upper)
36. Heelboard assembly
37. Seat-pan assembly
38. Spare-wheel floor assembly
39. Squab cross-brace assembly
40. Front-valance assembly N/S
41. Dash-pan assembly
42. Windscreen panel (SH Saloon)
43. Windscreen lower rail
44. Windscreen hinge-bracket assembly
45. Upper-panel shroud assembly (Inner) N/S
46. Drip moulding (front) N/S
47. Drip moulding (roof) N/S
48. Side panel N/S
49. Wheel-arch filler N/S
50. Lower-panel shroud assembly N/S
51. Front-door assembly N/S
52. Rear-door assembly N/S
53. Side-header reinforcement N/S
54. Sliding-roof channel assembly
55. Sliding-lid assembly
56. Roof panel (SH Saloon)
57. Parcel shelf
58. Quarter-light reinforcement O/S
59. Trunk-panel assembly
60. Trunk-opening reinforcement
61. Trunk-floor side support N/S
62. Trunk-lid assembly
63. Spare-wheel clip
64. Spare-wheel lid assembly

line, and also that of the subassembly lines in order to ensure a balanced flow of units to every station.

The time occupied by each operation must also be carefully estimated and allowed for in the layout. Unless this is done, the production schedule may soon become unbalanced, with the result that work piles up at some stations, whilst at others operators are standing idle.

Such difficulties are overcome in several ways. It may be practicable to give an operator two or three simple operations to perform in order to balance his time with that of a more lengthy operation elsewhere on the line. Another possibility is to duplicate the longer operations so that the two units are produced in the time required for one. It might be possible to reduce the time required for a long operation by increasing the number of men at the station, although this would not be successful if the station became so crowded that the men got in the way of each other. Sometimes, a carefully designed fixture would provide the solution.

In the case of moving tracks, the time occupied by each operation will influence the spacing of the stations. Naturally, if the operation is lengthy, sufficient distance must be allowed to enable the work to be completed before

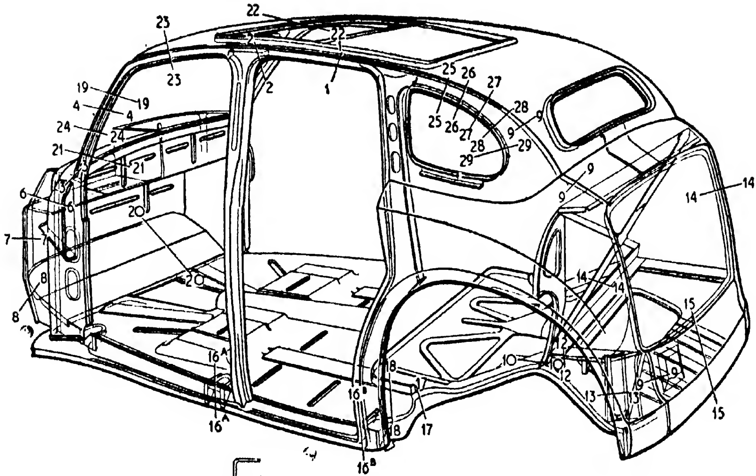


FIG. 2 (*above*).—PICTORIAL SKETCH OF A BODY MARKED TO SHOW THE SECTIONS FROM WHICH THE SUBASSEMBLY DRAWINGS ARE MADE

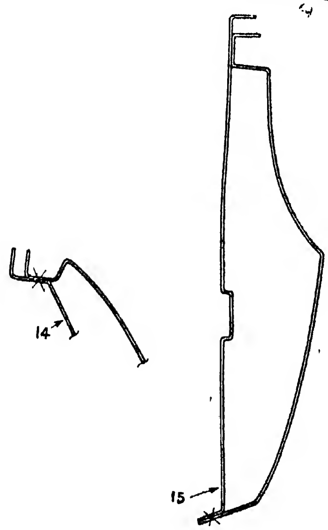


FIG. 3 (*left*).—SUBASSEMBLY DRAWING SHOWING THE POSITIONS OF THE WELDS

it reaches the next station. From this it will be seen that the ideal to be aimed at is to plan the work so that, as far as possible, the time occupied at each station is the same.

FIXTURES

The design and manufacture of fixtures usually proceeds simultaneously with planning of the shop layout. In simple language, a fixture (Fig. 4) comprises equipment designed for holding work whilst an operation, in this case welding, is performed on it. Apart from isolated instances, every fixture is specially

FIG. 4.—A SIMPLE WELDING FIXTURE INCORPORATING COPPER BACK-UP STRIPS ("*Welding*")

designed for one specific workpiece or operation, and is rarely suitable for any other workpiece or operation. However, it is often possible to incorporate standard parts which may be used again and again in different fixtures.

A welding fixture has two main functions. Firstly, it must locate the parts accurately relative to each other or to some datum point so that, when welded, the parts are correctly positioned in relation to the whole unit or subunit. Secondly, the fixture must hold the work securely during the operation. The provision of means for quick loading and unloading is essential, particularly as in many instances this occupies more time than the actual welding operation.

Progressive Building

The policy of "progressive building" favoured by some firms provides a useful guide to one important modern trend in fixture design. This scheme comprises the use of a main fixture designed to incorporate several removable subfixtures, so that a major unit can be built up by progressively adding smaller components. This has the special advantage of reducing costs by enabling one basic fixture to be used for a range of operations normally requiring several expensive fixtures.

The first component or components are placed in the basic or main fixture and, after completion of welding, a smaller subfixture is added to allow another part to be welded to it. As a rule, means are provided on the main fixture to

locate the subfixture accurately, so that the second component is correctly positioned relative to the first component. Subsequent stages vary according to the shape of the unit being welded.

To facilitate welding, the main fixture is sometimes mounted on trunnions, so that it can be swung over in the horizontal plane to enable operations on the underside, or pivoted to allow rotation in the vertical plane. Often, both movements are incorporated in the one fixture. Should the layout of the shop necessitate movement of the fixture from station to station, it would be mounted on wheels or castors (Fig. 12).

From the production viewpoint, this type of fixture has important advantages. In particular, loading and unloading times are considerably reduced, and it is generally possible to reduce the number of operators and welding equipment.

WELDING EQUIPMENT

Apart from a comparatively few instances, "spot" or electric resistance welding is employed exclusively for body assembly. This equipment may be either of the fixed or portable type, the latter being employed much more extensively than the former.

For our purpose, portable equipment may be considered to comprise two portions: (*a*) the transformer suspended overhead, and (*b*) the welding gun connected to it by cable, the latter incorporating an air-operated cylinder for actuating the electrode to apply the necessary mechanical closing pressure. Each body-assembly department may require possibly 50–100 portable welding sets, and if several different models are in production at the same time, the total number is considerable.

In one large British factory the two main types of welding equipment comprise 50-kVA pedestal-type spot welders and 75-kVA portable equipment. The fixed machines are used almost entirely for smaller work which, together with their fixtures, can easily be manhandled by the operator. This equipment is nearly always fully automatic, i.e. the operator merely depresses a switch in order to set the welding cycle into action, and has no control over the actual sequence

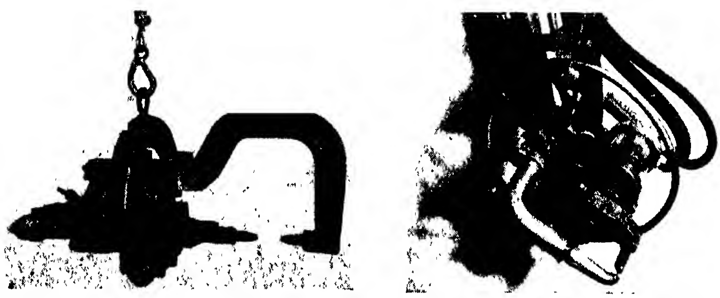
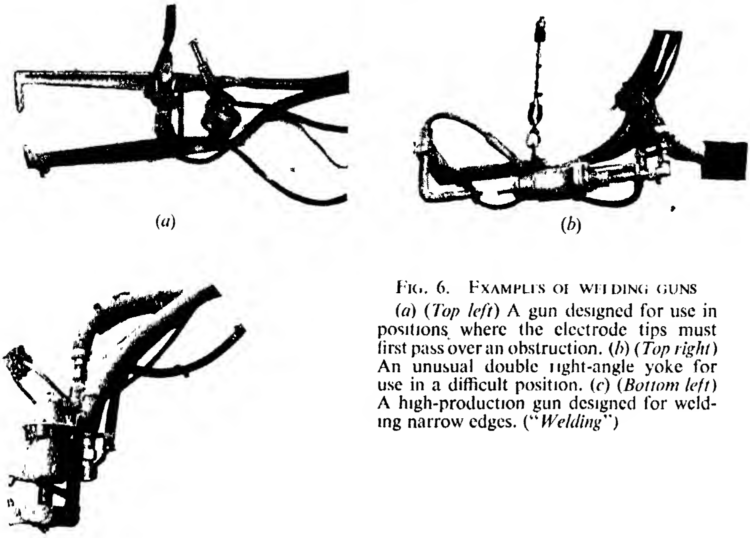


FIG. 5.—TWO TYPES OF GUNS MOUNTED IN RINGS TO FACILITATE ROTATION DURING USE ("*Welding*")



(a) (b) (c)

FIG. 6. EXAMPLES OF WELDING GUNS
(a) (*Top left*) A gun designed for use in positions where the electrode tips must first pass over an obstruction. (b) (*Top right*) An unusual double right-angle yoke for use in a difficult position. (c) (*Bottom left*) A high-production gun designed for welding narrow edges. ("*Welding*")

of the cycle. Although 100-kVA equipment may be necessary for heavy-gauge components, most of the work can be done with the lighter 75-kVA machines. The portable types of spot welders are mostly employed for larger or bulky work which is difficult to handle, or in cases where a complicated jig is necessary.

Three essential factors must be considered regarding welding equipment intended for use under mass-production conditions, i.e. high efficiency, the need for strong and light machine construction, and ease of maintenance. For this reason, most of the larger firms build their own equipment, including not only welding guns and machines, but also the various types of ancillary equipment, such as transformers. The standardisation of parts throughout the factory is a policy also adopted by most firms, as it enables repairs to be effected very quickly, and makes possible the building of special equipment relatively cheaply and without undue delay.

By standardisation, interchangeability has also been achieved, and it is possible to use most of the parts on any of the welding equipment. Interchangeable items include handles, air cylinders, pistons, air controls, electrodes and electrode holders, yokes. One firm has even standardised the transformers and weld timers.

Special Equipment

In addition to the standard types of welding equipment, every firm has developed special types in order to facilitate production or to overcome the

various difficulties encountered from time to time. For example, in some cases it is necessary gradually to rotate the gun during use, as when welding around the semi-circular ends of window frames. Because of the obstruction caused by the cables and pipes, such rotation is both difficult and fatiguing, and various types of holders have been designed to make the work easier and thereby increase output.

In the design developed by one firm (Fig. 5 (*a*)) the gun is arranged inside a ring which is mounted on ball bearings in an outer ring, rotation being further facilitated by the provision of a large handle. Another firm has overcome the difficulty by encircling the gun with a steel ring (see Fig. 5 (*b*)) which is suspended on an overhead hanger by means of a wheel. Rotation can thus be effected with very little effort on the part of the operator.

Another interesting gun (Fig. 6 (*a*)) has been developed for use in cases where the electrode tips must pass over an obstruction before they reach the welding position. The design is such that movement of a handle at the top, through simple linkage, causes the tips to open sufficiently to pass over the obstruction. Once in position, the handle is moved to return the arms to their normal welding position, i.e. with the tips approximately $\frac{3}{4}$ in. apart. Further movement of the tips for the purpose of welding is obtained in the ordinary manner from the air cylinder.

Seen in Fig. 6 (*b*) is an unusual gun developed for use in difficult enclosed positions. The yoke incorporates a double right-angle, the design being such that it is possible to insert the electrodes in an enclosed space and weld the rear side of panels which are inaccessible by normal means.

The gun in Fig. 6 (*c*) has been specially designed for welding narrow edges: the light head and short electrode movement enables a high production speed. The use of yokes specially shaped to suit difficult positions is, of course, quite commonplace.

A useful feature introduced by one firm is a patented transformer which ensures that the welding cycle must be completed before the electrode tips will separate. If, for any reason, welding does not take place, the tips remain locked, and further work is impossible until repairs have been effected. This device prevents the production of work which would be rejected at a later stage because of missing or incomplete welds.

"Back-up" Strips

When welding sheet metal by the "spot" or electric resistance welding process, unsightly indentations are generally produced on the surface of the work due to the mechanical pressure of the electrode tips as they nip the pieces together. Often this is unimportant, but when an external surface is concerned, it is generally desirable to avoid such markings. In the past, in order to achieve this it was customary to cover the electrode markings with solder, which was then filed to blend with the contours of the body. This extra work increased production costs considerably and wasted valuable man-hours.

For this reason, increasing use is now being made of a system whereby any

welded surfaces which must be free from indentations rest on a flat copper strip or bed, the bed and work being then gripped between the electrodes. If the work is being welded in a fixture, it is usual to incorporate the copper strips as a permanent part of the design. If fixtures are not employed, the strips may be held in position with clamps so that, when the operation is completed, they are easily removed and transferred to the next component.

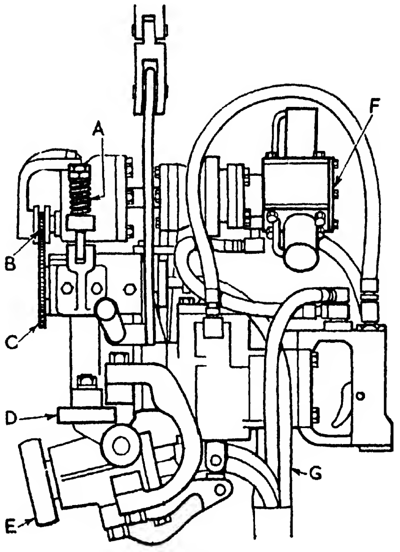


FIG. 7.—SKETCH SHOWING THE MAIN FEATURES OF THE ROLLER SPOT WELDER

(*a*) Tension spring; (*b*) driving wheel; (*c*) electrode wheel; (*d*) guide wheel; (*e*) collector wheel; (*f*) air motor; (*g*) water, air, and current cables.

Roller-type Equipment

A very important development has been the introduction by a British firm of a 75-kVA portable roller-type spot welder (Fig. 7), designed specially to avoid the markings resulting from the pressure of the electrodes of the normal type of spot-welding machines. It is automatic and very quick in operation. Although welding is done with a wheel-type electrode, the equipment is definitely a spot welder, and not a stitch or seam welder, because of the fact that the welds do not overlap, nor are they closely spaced. Actually, they are made at the rate of approximately three evenly spaced spots per inch.

This equipment has been developed for mass-production work, and is essentially for use in conjunction with welding fixtures. In use (Fig. 8), the machine is suspended at the side of the fixture on a self-winding reel which allows it to move up and down with minimum effort by the operator, the reel itself being free to move on a pulley along an overhead rail. This equipment is intended for use with a copper strip or bed, which is connected to a 75-kVA water-cooled transformer by water-cooled cables.

The current is collected from the bed by a wheel incorporated in the equipment, and then passes via copper laminations up through the machine body to a rotating copper electrode wheel. From here, it flows through the two thicknesses of steel which are to be welded, back to the bed, i.e. the return side of the transformer. The edge of the electrode wheel is knurled to reduce chances of slippage on the work surface, and is rotated by a smaller wheel mounted on a

shaft driven by a reciprocating-type air motor fed at a pressure of 100 lb. per square inch. The arrangement is such that the speed of welding is approximately 6 ft. per minute.

Some of the work for which the equipment has been designed (see Fig. 8) is curved in two planes, and the copper bed is specially shaped to ensure that the electrode follows the necessary path. In the case of the horizontal plane, a steel guide-wheel on the side of the equipment is in contact with the curved side of the copper bed. In addition, the collector wheel is in contact with the lower edge of the bed, which is curved to suit the vertical profile of the work. When welding, it is only necessary for the operator to push the equipment up to the work, the rotating electrode wheel then pulling it along the path to be welded.

Often, two such equipments are in use simultaneously, thus allowing two edges of the work to be welded at the same time as, for example, when welding the drip mouldings on the roof (Fig. 8). It has been stated that on one particular operation this useful equipment has reduced the welding time by 60 minutes, this saving being due to the quicker rate of welding and also to the elimination of any need for soldering and trimming to hide electrode marks.

Poker Welding

An example of the "poker-welding" technique is provided in Fig. 9, which shows its use when securing clips for pipes and electric cables to the floor assembly. Because these clips are situated near the centre of the floor, it would be difficult—if not impossible—to reach the welding position with any normal type of equipment, because the yoke would be too clumsy and heavy. For this reason the poker, or "push-gun," process is employed, but it must be observed that this type of welding is suitable only for non-stressed work.

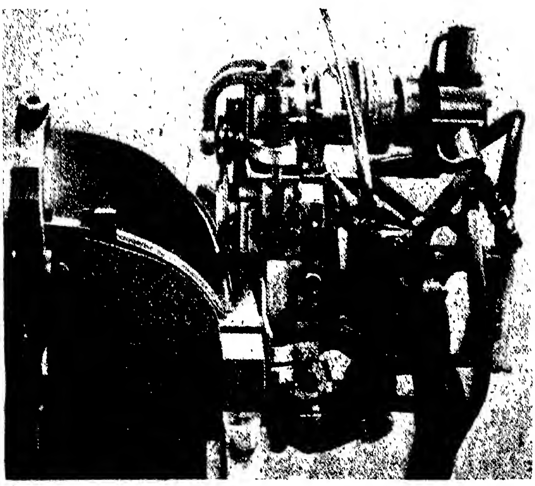


FIG. 8.—SHOWING HOW THE ROLLER SPOT WELDER IS USED FOR SPOT WELDING THE DRIP MOULD ON THE EDGE OF THE ROOF ("*Welding*")

FIG. 9.—THE USE OF "POKER WELDING" TO SECURE CLIPS IN A POSITION DIFFICULT TO REACH WITH NORMAL EQUIPMENT (*The Nuffield Organisation*)

One secondary lead is clamped to the edge of the floor and the other terminates at the "push gun," inside which the electrode is supported by a spring. In use, the gun electrode is placed on the work, and the gun forced downwards until the 60-lb. pressure of the spring is overcome; this operates contacts which cause the current to flow through the electrode for a predetermined period, thus completing the "spot."

Other Welding Processes

Seam welding is employed only to a limited extent in the automobile industry; in fact, many firms do not use the process at all. Where employed, it is generally reserved for such operations as assembling petrol tanks and sumps.

Projection welding is generally confined to relatively small work, such as securing nuts, bolts, and clips to sheet metal. Where suitably employed, considerable time savings are possible. For example, one firm now welds a mild-steel washer inside a nut by this process, achieving an output of 300 per hour, this being considerably higher than the output previously possible when the operation was performed by soldering.

Comparatively little use is made of flash-butt welding, although some firms

employ it for such operations as joining roof portions together. In general, it is confined to joining simple, flat work, although in one case the process has been adapted for welding the two parts comprising the front wing.

The remaining welding methods, such as the electric metallic arc, oxy-acetylene, and atomic hydrogen processes, are only employed in relatively few cases.

PRACTICAL EXAMPLES

The general principles outlined above can best be understood by examination of the layout and production methods actually employed by some of the leading British automobile manufacturers.

The diagram in Fig. 10 illustrates the layout of the Body Shell Assembly Department of a large firm. As the name implies, the expression "body shell" or "outer body shell" refers to the outer steel shell of the body prior to the addition of any internal fittings, upholstery, and so on. With some models the expression "body shell" includes the chassis, but in the particular case under review, the chassis is a separate unit and not integral with the body.

To make the best use of the floor space, a double U-shape main assembly track is employed. Power-driven at a speed of 39 in. per minute, it is designed to give an output of 500 bodies per forty-hour week, assuming 80 per cent. efficiency. This is based on a four-minute work cycle, i.e. all operations at each station are completed within four minutes. Only fourteen stations on the line are concerned with welding.

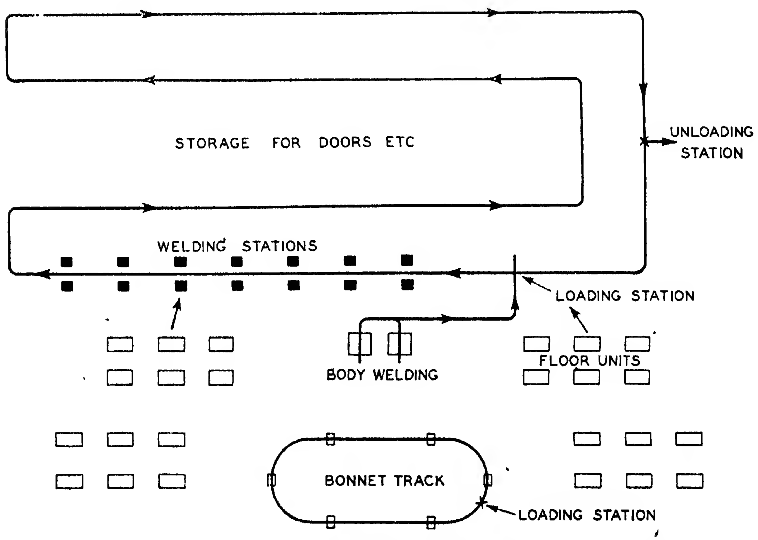


FIG. 10.—LAYOUT OF THE BODY SHELL ASSEMBLY DEPARTMENT OF A LARGE MODERN FIRM

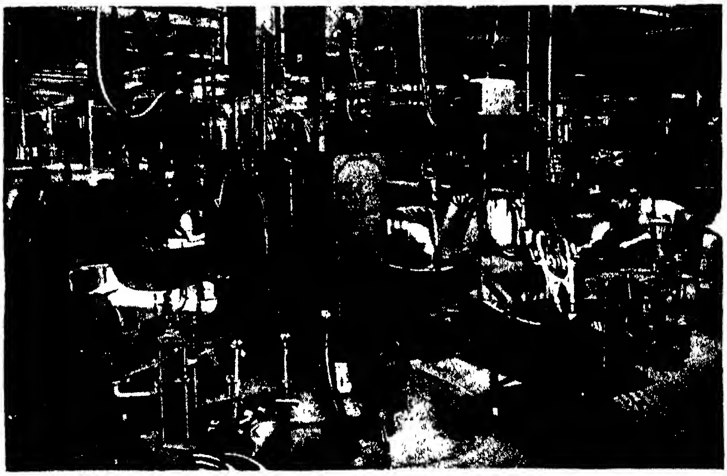


FIG. 11.—SHOWING THE SELF-CONTAINED OVAL-SHAPED BONNET ASSEMBLY TRACK ("*Welding*")

For final assembly (Fig. 14) the shells rest on specially designed bogies running on flat strips of steel secured to the floor. Projecting from the upper framework of the bogie are fixed pins which enter certain holes in the underside of the floor to locate it in the correct position, further location being provided by three pads, on which the body floor rests. Bogie movement on the track is provided by a central endless towing chain.

Subassembly Track

In this particular factory the subassembly sections are situated on one side of the main assembly line. One of these comprises a small self-contained oval track (Fig. 11) for assembling the bonnet, a unit consisting of seven parts. Spaced around the track are four electric welding stations, one gas-welding station, and the loading station. The actual track comprises a single oval of channel iron, which guides the movement of mobile fixtures mounted on three castors, the outer pair of which run inside the channel. This track is not power driven, the six fixtures being pushed from station to station by hand.

The fixtures incorporate supports suitably shaped to accommodate the contours of the bonnet and locate the parts in their correct positions. On the supports are quick-action clamps to hold the components during welding: they are of simple design, a single movement of a lever-type handle being sufficient to lock them firmly.

To prevent unsightly indentations, the tips of the clamps are provided with a pad shaped to correspond to the work contours at the point on which it

presses. Directly underneath the point of clamping, the work rests solidly on steel supports shaped to suit the contours of the underside of the panel. This method of support is essential at every clamping station, otherwise serious distortion of the comparatively thin panels would result.

At the loading station, the main parts of the bonnet are secured in position and the fixture then pushed, in turn, to the remaining stations, where they are welded together and various stiffening pieces added.

Floor Fixture

A different scheme has been adopted for assembling the floor unit (Fig. 12). In this case the parts are loaded in a fixture mounted on four castors which can be freely pushed to any position. Suspended overhead are the guns necessary to complete the various welds, and the fixture is moved from one to another. Actually, two such fixtures are employed, one being loaded or unloaded whilst the other is in use.

Body Fixture

Some idea of the complicated nature of the larger welding fixtures may be seen from Fig. 15, which shows the equipment in which the major portion of the body is assembled, i.e. practically the entire unit except the floor, bonnet, and certain small parts. The various subassemblies used in the fixture are brought from adjacent sections and accurately located in the fixture so that each is correctly positioned in relation to the body as a whole. A duplicate fixture is provided so that one can be loaded whilst welding is in progress on the other.

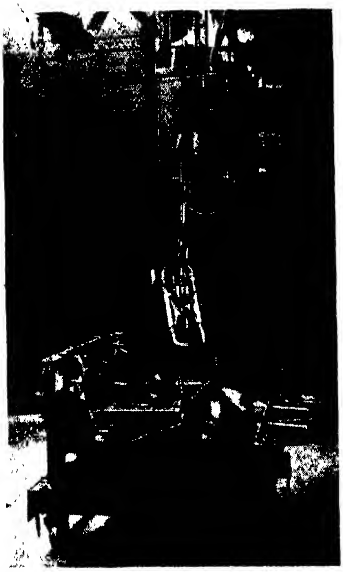


FIG. 12.—A USEFUL EXAMPLE OF A MOBILE FIXTURE WHICH CAN BE FREELY MOVED FROM STATION TO STATION ("*Welding*")

Main Assembly Track

On the main assembly line the floor unit is first laid on the bogie mentioned previously, and the body, brought by overhead monorail from the fixture in Fig. 15, then lowered on top. With the aid of quick-action clamps, various subfixtures are attached to provide support and location at various important positions, such as the door-hinge holes and bonnet lines.

As the body moves along the first section of the track (Fig. 16), it passes through an avenue of overhead

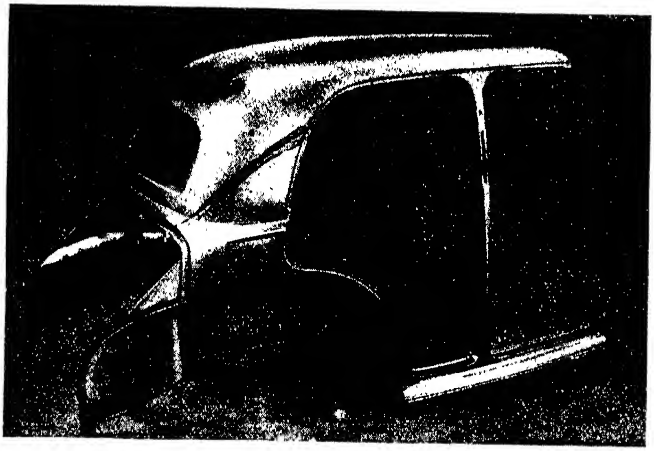


FIG. 13A.—REAR-END ASSEMBLY

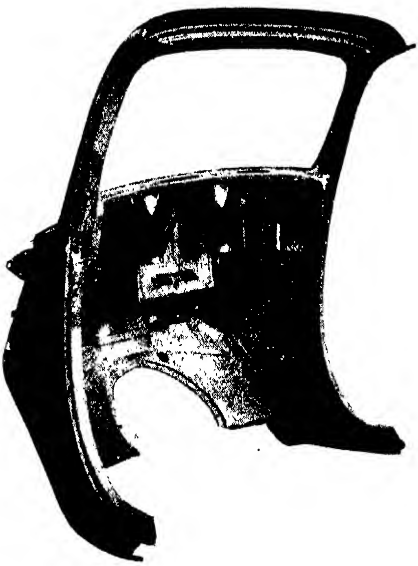


FIG. 13B.—BULKHEAD ASSEMBLY

NOTE.—It will be seen from these illustrations that the rear-end assembly (Fig. 13A) and the bulkhead assembly (Fig. 13B) each consists of a number of components welded together. Further stages in the building up of the bodywork are illustrated in Figs. 15 and 16. ("*Welding*")

spot-welding guns, where a variety of operations are performed. When it turns into the second section, certain gas-welding operations are carried out, the body then continuing through the remainder of the fifty-three stations for fitting of the doors, rear lids, and so on, and the many body-finishing stages, such as soldering and grinding. At the last station it is lifted from the fixture to spray the under portion with sound-deadening solution, and then transferred to an adjacent paint conveyor track.

STRAIGHT-LINE TRACK

The layout of the Body Shell Department at another factory is given in Fig. 14. This time sufficient floor space is available to permit the use of a straight-line track. The various subassembly units are produced on short tracks or small sections specially laid out and situated either adjacent to the main tracks or on the floor below, from which the parts are brought up by hoist.

In order to follow the operation of this assembly line, it is necessary first to consider the manner in which the body is split up into units. The body under review comprises four main subassemblies (Fig. 13), which are brought together at the final assembly line. These are: (1) the front end, (2) the rear end, (3) the underbody, and (4) the bulkhead. The rear-end unit incorporates two wheel arches, two centre pillars, and the roof.

Two types of welding are employed in this fixture, i.e. oxy-acetylene for joining the wheel arches to the roof panel, and electric spot welding at the top and bottom of the central pillars.

When loading the fixture, the roof panel is placed in position first, and laid on suitably shaped locating supports incorporating a ledge on which the rear end of the roof panel rests Inside the fixture (Fig. 17) are two blocks shaped to suit the internal contours adjacent to the weld line at the junction of the

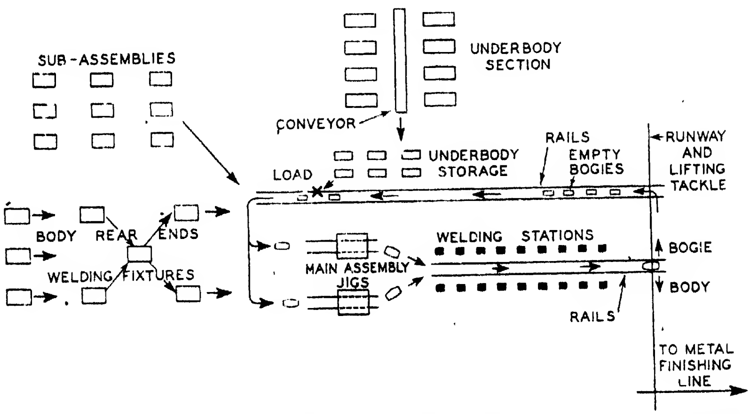


FIG. 14.—IN THIS CASE, SUFFICIENT SPACE IS AVAILABLE TO ALLOW THE USE OF A STRAIGHT FINAL ASSEMBLY LINE

FIG. 15.—TWO STATIC BODY-ASSEMBLY FIXTURES. ONE IS LOADED WHILST WELDING PROCEEDS ON THE OTHER ("*Welding*")

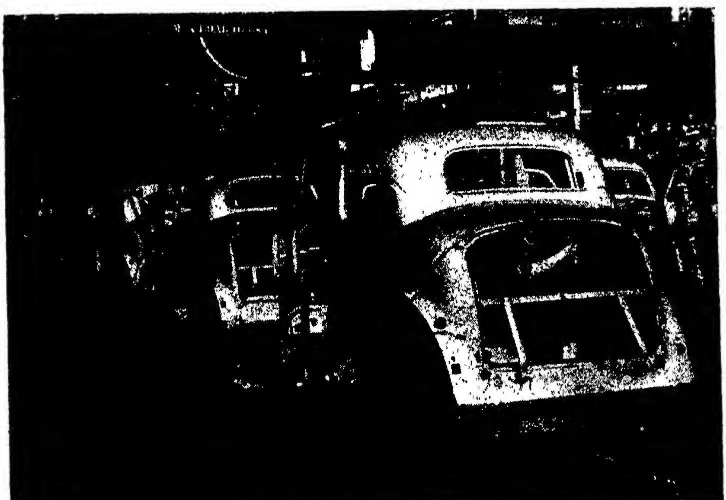


FIG. 16.—THE SPOT-WELDING SECTION ON THE FINAL ASSEMBLY LINE ("*Welding*")

roof panel and wheel-arch units. By means of pneumatically-operated mechanism controlled from a small lever, these blocks can be made to move inwards to facilitate removal of the body after completion of welding. From the illustration it will be seen that there are also two external hinged clamps, which are shaped to correspond to the external contours of the body surface adjacent to the welding area each having a narrow slot corresponding to the weld line.

Before loading the parts into the fixture, the two internal supports are moved outwards to their normal position, and when the various body components are correctly located, the external clamps are swung over by hand until they nearly touch the work surface. At this position a trip lever automatically brings hydraulic mechanism into operation to tighten the clamps firmly against the panel, i.e. grip the panel between the clamps and internal supports. It will be noticed that the clamps contain a very considerable volume of metal, and thus absorb much of the heat radiated from the welding area. This, together with the very rigid method of holding the parts, reduces to a minimum distortion caused by the welding heat. Four operators work simultaneously, i.e. two gas welding the wheel arches and two spot welding the centre supports.

Final Assembly Line

As completed, the rear-end assemblies are stacked adjacent to the commencement of the main assembly line. The front-end unit—made on the floor below—is brought up by hoist through an opening in the floor, and the bulkhead unit—also made elsewhere—is stacked in a suitable position adjacent to the main assembly line. The remaining major unit, i.e. the underbody, is produced in a section situated near to the main line.

From the layout it will be observed that there is a second track parallel to the main assembly line, and on this are bogies mounted on castor wheels and incorporating provision for locating the underbodies which, as completed, are loaded on to these bogies. The rear-end unit is then placed in its approximate position on the underbody, and the bogie moved along a short length of track into the main assembly fixture. By means of air-operated mechanism, the section of the track inside the fixture is then dropped for a few inches, this allowing the bogie to rest on cast-iron pads to ensure that the underbody is located at the correct height relative to the fixture. At the same time, two fixed pins projecting from the bottom of the bogie enter holes in the pads, thus accurately positioning the bogie, i.e. the underbody, in the fixture.

This main assembly fixture (Fig. 18), in which most of the welding is performed, is a sturdy channel-iron structure built astride the track, and incorporating devices for ensuring correct location of the four units which are to be welded together. At the front end are two hinged doors, one on each side, which can be swung open to provide access to the interior for loading purposes. On the edge of the doors are various locating devices to ensure accurate positioning of the front-end unit.

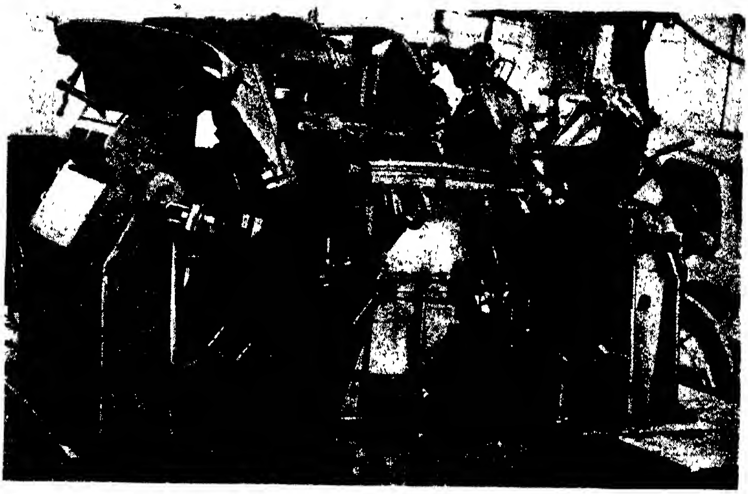


FIG. 17A.—UNLOADED VIEW OF THE FIXTURE IN WHICH THE REAR-END UNIT IS WELDED

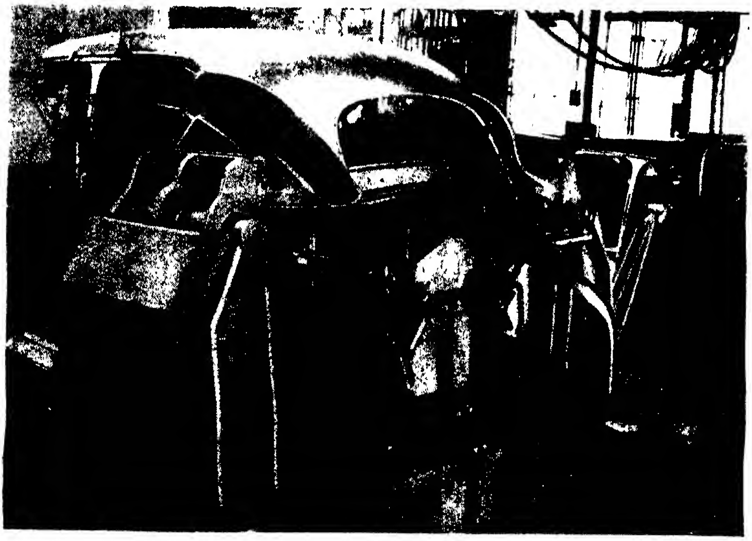


FIG. 17B.—ILLUSTRATING THE SAME FIXTURE, BUT THIS TIME WITH THE REAR-END UNIT IN POSITION

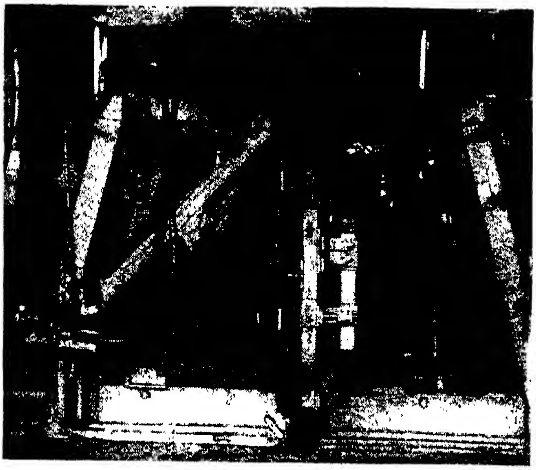


FIG. 18.—SOME IDEA OF THE COMPLICATED DESIGN OF MAIN ASSEMBLY JIGS MAY BE GATHERED FROM THIS EXAMPLE
("*Welding*")

At the top of the front end of the fixture is a hinged, counterbalanced clamp which secures the top of the front-end assembly and presses it back against the various locating pins: it can be swung upwards to facilitate removal of the body when unloading the fixture. At the front of the fixture is a hinged platform on which the operators stand to reach the higher portions at this end of the body: after completion of welding, it is swung to one side to allow the body to leave. Suspended around the fixture are six welding guns, i.e. two for

FIG. 19.—THE MAIN ASSEMBLY JIG LOADED AND READY FOR WELDING THE BODY PARTS TOGETHER
("*Welding*")

FIG. 20.—GENERAL VIEW OF THE SELF-CONTAINED POWER-DRIVEN TRACK FOR ASSEMBLING THE FLOOR UNIT ("*Welding*")

Five of the stations on this track are concerned with gun-welding and minor gas-welding operations.

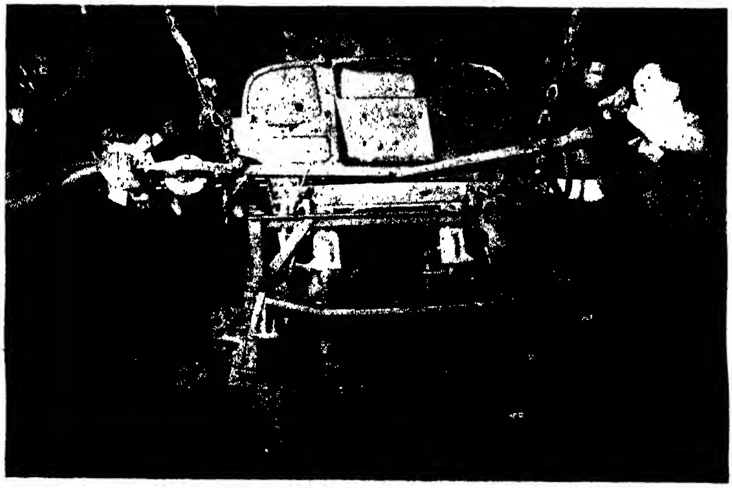


FIG. 21.—CLOSE-UP VIEW OF ONE OF THE FIXTURES USED ON THE FLOOR ASSEMBLY LINE ("*Welding*"

each side, one for the rear and one for the front. Whilst in the fixture, certain gas tack-welding operations are also performed.

After completion of the various operations the fixture is unloaded and the body pushed for a short distance until it engages projections from an endless chain, which then carries it past nine stations for certain other gas- and spot-welding stages. The speed of the track is set to give an output of fourteen bodies per hour. At the end of the track the shell is hoisted from its bogie, transferred to another type of bogie, and pushed by hand to the "metal-finishing" lines, where it is moved automatically past the various stations by an endless chain: whilst on this line, the doors, luggage-trunk lids, and such items are added, and the various metal-finishing operations performed.

A COMPACT LAYOUT

The layout of a third body shell assembly line is seen in Fig. 22. In this particular model the design of the single-piece floor is such that the need for a separate chassis is avoided. An outstanding feature of the shop layout is the exceptionally compact arrangement of the equipment, which allows all subassembly and final assembly operations to be performed in an area measuring only 300 × 120 ft.

The body has been split into four main units or subassemblies, i.e. floor, forward end, body outer shell, and doors, each of which are produced in self-contained sections situated at the side of the main track. These differ from most of those described previously, because they all incorporate moving subassembly tracks, either straight or oval. All these tracks are power driven and timed to handle an output of 20 units per hour.

Floor Assembly

The first subassembly section is concerned with assembling the floor unit, part of the oval power-driven track being seen in Fig. 20. Five of the stations are

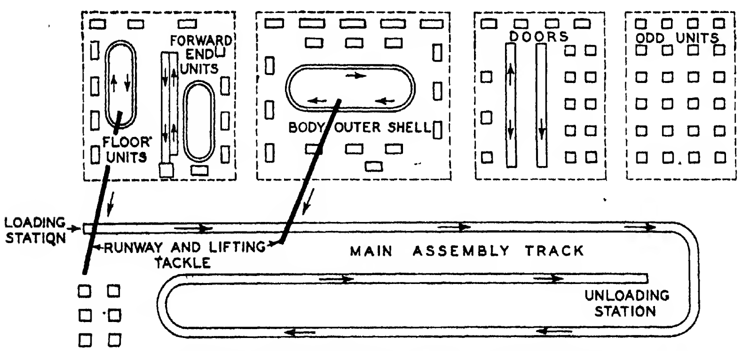


FIG. 22.—THIS DIAGRAM PROVIDES A PARTICULARLY INTERESTING EXAMPLE OF A VERY COMPACT LAYOUT

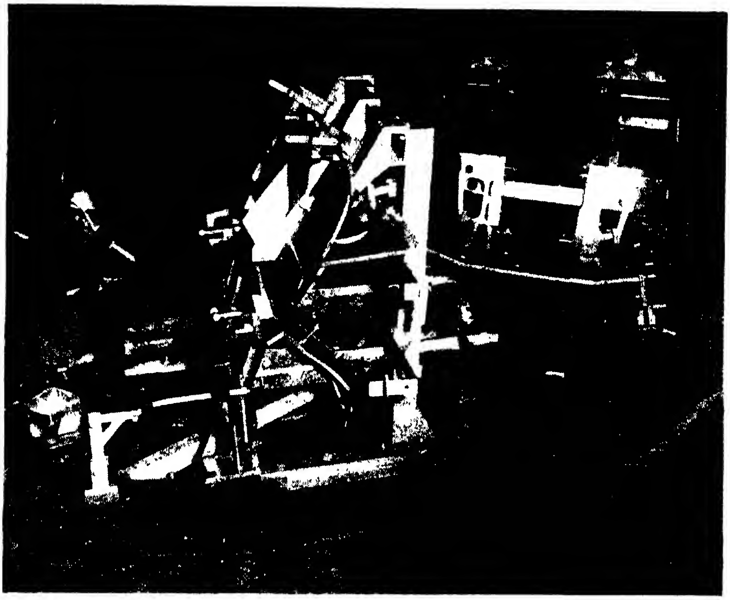


FIG. 23.—PART OF THE FORWARD-END SUBASSEMBLY TRACK, SHOWING THE DESIGN OF THE FIXTURES ("*Welding*")

FIG. 24.—THE BODY OUTER SHELL TRACK ("*Welding*")

concerned with gun-welding and minor gas-welding operations, and it is interesting to note that some parts of the unit are tied to limits of $\frac{1}{32}$ in., which is very close for work of this nature. On this track use is made of two articulated guns (Fig. 6 (*a*)) which are required to pass over high ledges in order to reach the welding position. Location of the unit in the fixture is from two press-tooling holes at the front end, which fit over pegs projecting from the front of the fixture. In addition, on each side is also a peg through the rear-spring shackle bracket hole.

Forward-end Assembly

The adjacent subassembly section is concerned with producing the forward-end unit, and comprises two tracks, i.e. a straight roller track for assembling the longitudinal members, which are then passed to the adjacent oval power-driven track (Fig. 23). On the roller track, six small jigs are rolled from gun to gun, side movement being prevented by two guide rails. The work is located in the jigs by a pin through the torsion-bar hole, and rests on supports. Some parts of this particular unit are only tacked by gun, and thus the components continue to an arc-welding booth situated at the end of the line, the empty jigs being returned along the parallel roller track (seen in the foreground) to the head of the line for reloading.

Body Outer Shell Assembly

The next section (Fig. 24) is concerned with assembly of the body outer shell on an oval track having eight stations. From the layout diagram (Fig. 22) it will be seen that around the track are situated various benches and welding equipment for producing the subassemblies for this unit.

One of the final operations on the track consists of welding the quarter and door facing panel to the roof-panel drip mould. To ensure that the surface is free from electrode indentations, a special gun and electrodes are employed, the latter being a flat, chisel shape, the top electrode exactly fitting the cross section of the drip mould. For inspection, these welds are subjected to a very severe test, consisting of driving a chisel between the two surfaces which have been welded together. As completed, the shells are transferred by runway direct to the assembly station on the main track.

Door Assembly Line

The next subassembly section is concerned with door production. This time there are two parallel wooden slat-type conveyors, with fixed locations screwed to their upper surface and both moving at the same speed. As the components move down one of the lines they pass a battery of gun welders with which the various operations are performed, and at the end the work is inspected and transferred to an adjacent row of benches for further hand operations. After completion and final inspection, they pass to the appropriate station on the main assembly line.

FIG. 25.—THIS VIEW ALONG THE MAIN ASSEMBLY LINE SHOWS HOW THE NEED FOR A COMPLICATED FIXTURE HAS BEEN AVOIDED ("*Welding*")

The Main Assembly Line

The main assembly line (Fig. 25) comprises inverted V-shape rails raised approximately 2 ft. above ground-level. It is interesting to note that the need for complicated jigs has been completely eliminated; instead, two grooved wheels are secured to the rear-spring front-shackle bracket holes of the floor unit, resting one on each rail. The unit is then moved along the track by hand

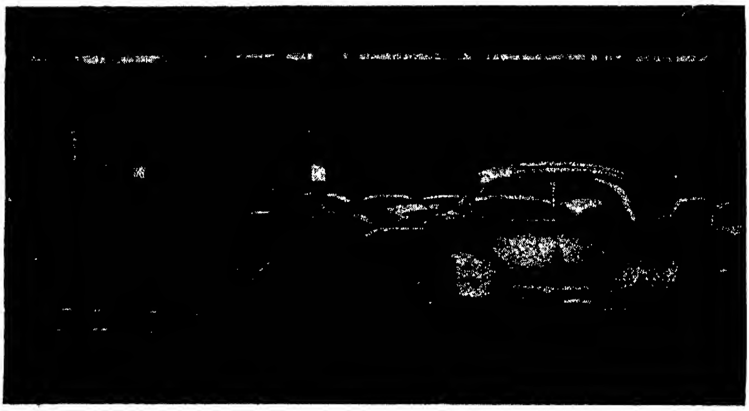


FIG. 26.—AN INGENIOUS FIXTURE DEVELOPED FOR CHECKING ALL THE BODY DIMENSIONS AND PICK-UP POINTS ("*Welding*")

through various stages until the forward end unit is added, after which it continues from station to station for the remaining operations.

Final Inspection

Fig. 26 shows the final-inspection jig on which every pick-up point and dimension on the body can be checked. The body is loaded on a table incorporating a number of datum points, the table then being moved along slides to the left, where it enters a framework containing further gauging equipment for checking the remaining dimensions. The high accuracy of the assembly operations may be seen from the fact that the dimensions from one end to the other are tied to limits of $\pm \frac{3}{32}$ in.

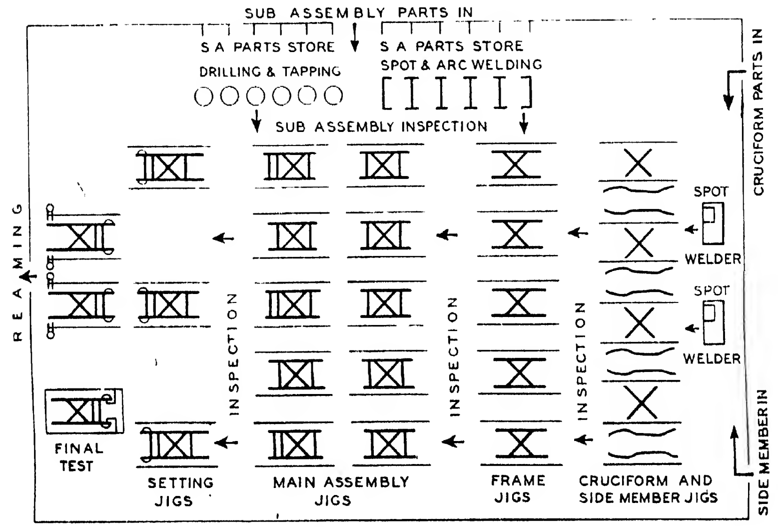


Fig. 27.—Layout of the assembly lines for the "Vanguard" chassis

CHASSIS ASSEMBLY

In many cases, the chassis is produced by "outside" firms specialising in this type of work. The methods of manufacture vary according to the requirements of the customer, some units being assembled mainly by spot welding and others by arc welding, or a combination of both processes.

The following description deals with the assembly of the chassis for the Standard "Vanguard," which is fabricated from parts pressed from 14- and 16-gauge mild-steel sheet. It provides an interesting example of the use of the arc-welding process for purposes of assembly under mass-production conditions.

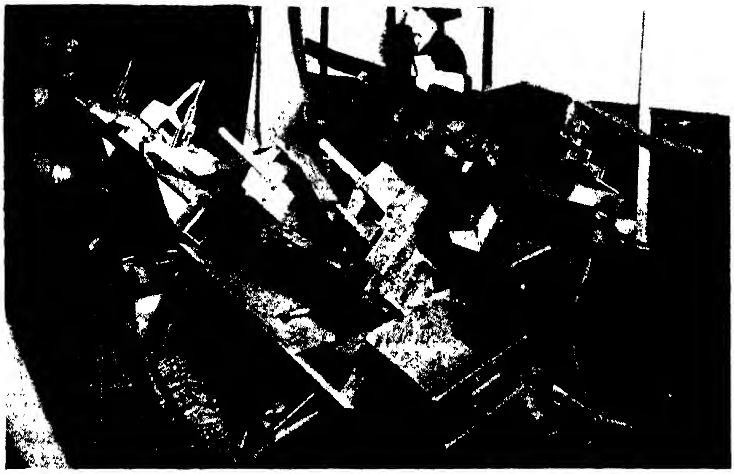


FIG. 28.—SIDE-MEMBER BOOTH, WHERE THE SUBASSEMBLIES ARE WELDED IN POSITION

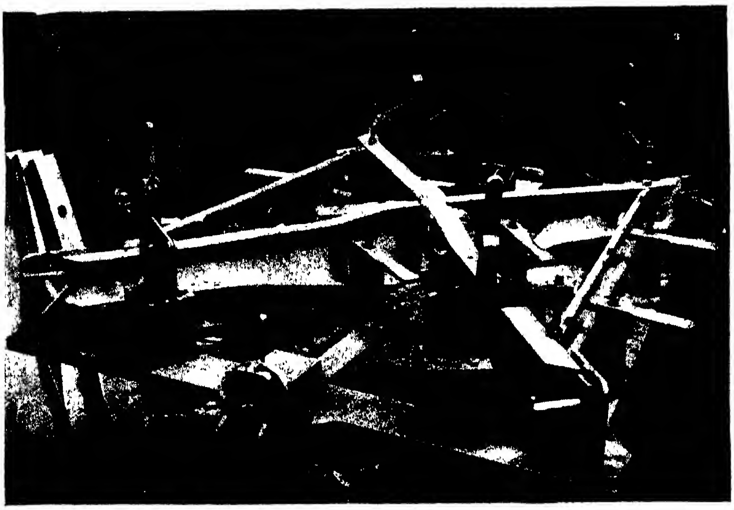


FIG. 29.—A CRUCIFORM ASSEMBLY JIG

From Fig. 27 it will be seen that the shop is laid out in a compact and efficient manner. The parts enter the chassis shop through three separate entrances. The main members, side-members, and cruciform members enter the head of the line, but the subassembly parts pass directly to the subassembly line running along one side of the main production line.

Spot welding is employed for the fabrication of certain small parts such as brackets. Larger and more complicated parts are fabricated from pressings by arc welding in a line of separate, screened booths. They enter the booths from the side gangway, are welded into complete subassemblies, and then pass out at the other side of the booth to the main production line.

Parts requiring drilling or tapping are handled on a conveniently situated line of machines. An interesting point about tapping, for which the parts are held in accurate jigs, is that a high-speed straight-through technique is used. As soon as the thread is formed, the tap falls freely from the chuck, to be replaced as the next workpiece is being loaded.

Main Assembly Operations

Cage nuts are spot welded to both the side and cruciform members immediately they enter the shop. This operation, performed at this stage because the chassis later assumes a box-section form making spot welding impracticable, illustrates the importance of carefully planning the sequence of welding operations.

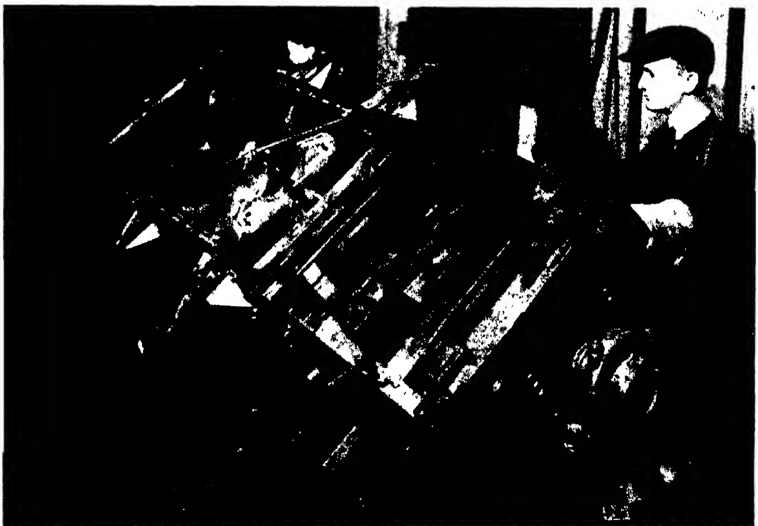


FIG. 30.—FRAME JIG IN WHICH SIDE MEMBERS ARE WELDED TO COMPLETE THE CRUCIFORM ASSEMBLY

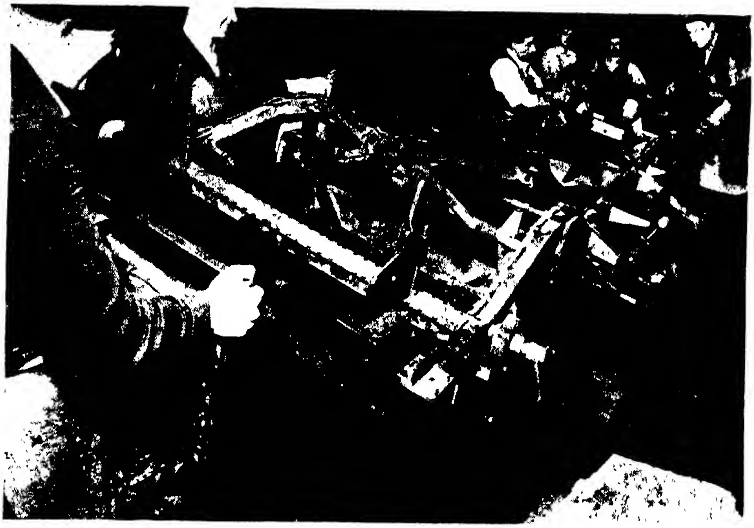


FIG. 31.—ONE OF THE FIVE MAIN ASSEMBLY JIGS

FIG. 32.—REMOVABLE JIG FOR LOCATING THE ENGINE MOUNTING BRACKETS

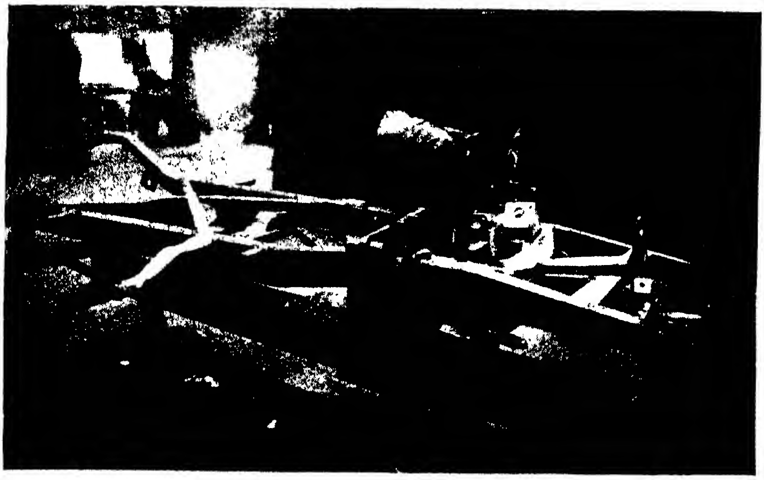


FIG. 33.—WELDING ON THE FINISHING JIG

From the spot welders, the side and cruciform members pass to a group of eight arc-welding booths. The first booth handles side members, the second the cruciform, and so on, so that the parts are favourably positioned for joining together. Two side members are handled at the same time in the side-member booths, one of which is shown in Fig. 28. The cruciform assembly jig (Fig. 29) is of the trunnion type, this design conforming with the general practice in this factory of positioning the work so that the maximum possible amount of welding can be done in the downhand position.

The side members, complete with front-bumper brackets, body, and jack-mounting brackets and rear-spring tubes, pass to an inspection section, and then on to meet the complete cruciform assemblies. In the five frame trunnion-mounted jigs (see Fig. 30) the side members are welded to the cruciform assemblies. It is important that all locations be accurately maintained throughout the production run, and the simplest way of ensuring this is to have a single point on the chassis from which all measurements are taken. To reduce the risk of possible errors, it is desirable that this single master check point should be located as near as possible to the midpoint of the chassis, and for this reason the pedal shaft location hole is used as the primary check point throughout the chassis production line.

Naturally, this applies also to the frame jigs, in which the chassis is located by the pedal-shaft location hole; here, two operators, working in booths separated by a central curtain, carry out all the necessary welding. In addition to rigid clamping in the jig, chances of distortion are further reduced at this stage by using the "skip-step-back" technique or, in other words, by welding

FIG. 34.—THE FLEXIBLE-SHAFT REAMER IN OPERATION

These reamers are used for reaming the rear tubes for the rear springs. The front brackets are reamed by hand.

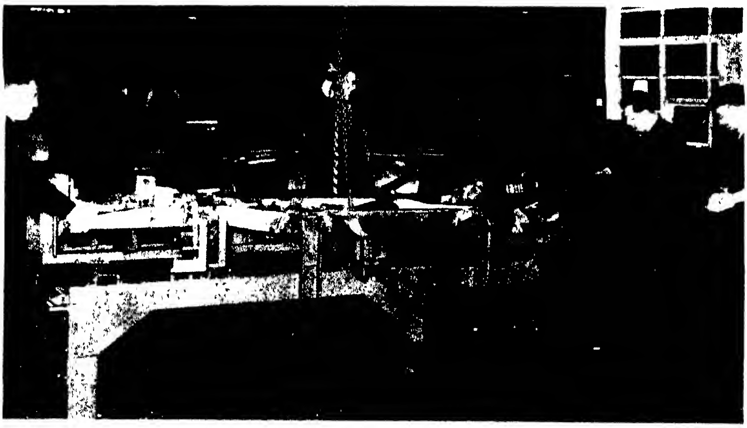


FIG. 35.—GENERAL VIEW OF THE PRECISION CHECKING JIG

The final inspection is carried out on this jig.

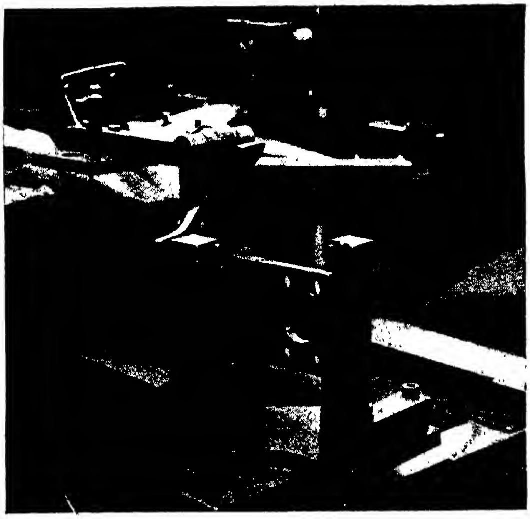


FIG. 36.—A SPECIALLY DESIGNED CHECKING GAUGE FOR INSPECTING THE ACCURACY OF THE COMPLETED CHASSIS

intermittently, each bead being laid from left to right, but the series of beads being worked from right to left.

From the frame jigs, the chassis pass first to inspectors and then on to five main assembly jigs (Fig. 31). On each jig four welders, again separated by raisable curtains, work as a team and weld in the front corner brackets, front and rear inner panels, steering cross-member, and the engine mounting brackets. The location of the engine mounting brackets is critical in relation to the corner abutments, and to ensure accuracy in positioning, removable jigs (Fig. 32) are loaded separately and then fitted into the main trunnion jig. The inner panels are the channel sections which, when welded to the channel side members, produce the final rigid box-section. Arranged in tandem with the main assembly jigs are further jigs of similar design—again served by crews of four—where additional welding is performed on those parts already positioned.

From these jigs the chassis move to special racks for inspection. These racks are constructed at different heights, so that valuable floor space is saved by the chassis being able to overlap each other without fouling. The units are now approaching completion, and after inspection of the welds they pass on to the setting jigs, where all locations and dimensions are checked, and in the case of any errors the jig responsible is at once examined for wear or damage.

Modern independent front-wheel suspension requires accurate positioning of the springs, and a simple method has been developed to ensure this replacement. The front corner brackets carry inside them abutment plates to which the ends of the coil springs will be fixed. The construction is such that these plates are free to slide $\frac{1}{32}$ in. in any direction up to this stage in the production.

The chassis are now mounted in the finishing jig, in which the abutment plates are located with absolute accuracy in a special fixture, and while in the fixture the plate is plug welded to the corner bracket so that there is no possibility of error.

Checking

After completion of all welding stages the chassis enters the reaming jig. Here, the bumper and engine mounting locations, and the position of the pedal-shaft location hole in the inner member, are checked, and the front brackets and rear tubes for the rear springs are reamed. The former are reamed by hand, but for the latter special flexible-shaft reamers (Fig. 34) have been installed. The tubes are reamed to remove "flash," ovality, and taper, if any, so that the bushings may be correctly fitted.

Final inspection now is the only remaining operation, this being done in a precision checking jig (Fig. 35). All pin gauges are designed to pass through the hole being checked, and must enter a socket on the other side in order to provide an extra check on possible errors. To make absolutely certain of the accuracy of the steering and suspension geometry, a specially designed checking gate is built into the main jig. This (Fig. 36) magnifies seven times any lateral or longitudinal errors in the positioning or setting of the steering and suspension components.

Acknowledgments

The author wishes to acknowledge with thanks the assistance given with data and photographs by *Welding*, the Lincoln Electric Co., Ltd., Vauxhall Motors, Ltd., Austin Motor Co., Ltd., The Nuffield Organisation, and Fisher & Ludlow, Ltd.

J. A. O.

MECHANICAL PRESSES IN ENGINEERING PRODUCTION

WITHIN the past decade there has been a vastly increased demand for a great variety of shaped components, particularly those made from the light metals and their alloys. This has led to the mass production of such components in different types of mechanical press best suited to the article to be made. In addition to the well-established processes of drawing and pressing, mechanical presses are being increasingly used in such operations as folding, flanging, perforating, blanking, and embossing.

The mechanically operated drop stamp may also be classed as a press, since its function is essentially that of shaping metal by pressure. Some fifteen years ago a new type of equipment, the rubber die press, was introduced to industry. As its name implies, this press makes use of rubber and the ability of the latter to form sheet metal to practically any required shape (see page 204).

In the majority of these pressing operations use is made of tools, or dies, shaped accurately to the contour of the component it is desired to produce. The necessary pressure for operating different presses may be obtained in several ways: it may be hydraulic pressure, or compressed air, or a purely mechanical pressure. In general, the best results are obtained by the use of either hydraulic pressure or compressed air, since with these the pressure may be applied very slowly and accurately controlled.

THE BLANKING PROCESS

With presswork, the necessary blanks from the sheet metal may be obtained either by shearing or blanking, the former method being used where cuts on straight and free edges only are involved. A rotary shear may be employed for producing circular or irregular shapes in small quantities, while the punch press may be used where large quantities of small parts are to be sheared. The high-speed router may be used for the cutting out of blanks for deep drawing. In blanking, the edges of a correctly formed blank are slightly tapered, the diameter of the blank decreasing from the die to the punch side of the sheet.

Power Requirements

Pressure needed in blanking may be calculated from the following formula: total force in tons $= PtS$, where $P =$ perimeter of the blank in inches, $t =$ thickness in inches, and $S =$ shear strength in tons per square inch.

The amount of power needed for a specific blanking operation may be decreased considerably by inclining the face of the die or punch; while in cutting ordinary blanks the inclined shearing face is ground on the face of the die, as seen in Fig. 1; but when cutting openings within the blank, or piercing large holes, the punch carries the shearing face.

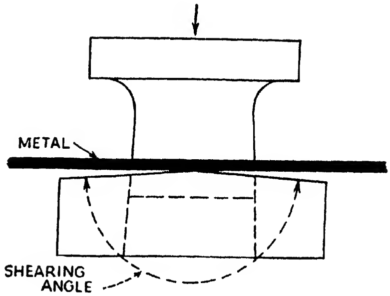


FIG. 1.—DIAGRAM OF BLANKING DIE WITH SHEAR GROUND ON THE DIE FACE

Blanking Dies

Dies for blanking light metals, such as aluminium alloys, may be made of hardened tool steel, or from a zinc alloy having the approximate composition 93 per cent. zinc, 4 per cent. aluminium, 2·7 per cent. copper, and 0·3 per cent. magnesium; while the punch for the alloys may be made of thick steel sheet.

Use of Cutting Rules

In addition to the better-known methods for blanking light alloy sheet, a procedure has been adopted which has long been used in the printing industry, the use of cutting rules, wherein the blanking tool is constructed from flexible tempered steel rule. The top edge of the rule is ground to a cutting edge with a single chamfer, as seen in Fig. 2. In this way the metal is cut at 90° on the work face, the scrap taking the crushing action on the chamfered side.

The steel cutting blades are mounted edgeways in a wood base, $\frac{5}{8}$ in. thick, the blades being bent to the desired shape. In aircraft factories blanking tools of this type are successfully used on 8–18 S.W.G. aluminium alloys at speeds of 750 blanks or more per hour, no appreciable wear being noticeable after many hours' work.

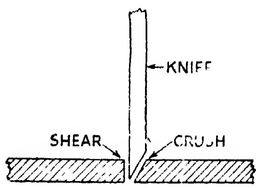


FIG. 2.—STEEL-RULE CUTTER FOR BLANKING ALUMINIUM-ALLOY SHEET MATERIAL

(*Aluminium Development Association*)

Multiple Piercing and Perforating

Perforating may be described as the piercing of a large number of closely spaced holes simultaneously, while piercing is the operation of blanking out small holes, such as rivet holes, in fabricated components of flat sheets. For multiple piercing and perforating special presses may be employed, although in many cases other presses are often adapted to this job. For example, standard punches can be inserted in a

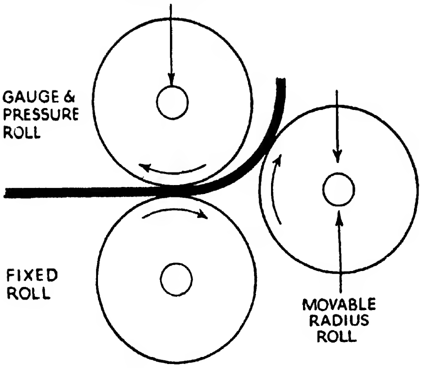


FIG. 3.—FORMING SIMPLE CURVES IN LARGE SHEETS BY ROLLING

brake press and used for the punching of long sections. In aircraft work piercing dies incorporating more than 300 punches have been successfully employed, and such technique requires accurate location of holes in the punch holder, stripper, and die.

BENDING

One method of forming simple curvatures makes use of three rolls, as in Fig. 3, the top roll being adjustable to gauge thickness and pressure, the bottom roll being fixed, while the other roll is adjustable vertically and deflects the sheet to the required arc. In the forming of long "V" shapes and more intricate patterns, the press-brake, or folding press, may be used, the machine producing the finished shape without appreciable alteration of thickness, width, or length of work.

The Press Brake

The press brake makes use of two dies, a female bolted to the bed of the machine, and the male, which moves vertically with the press ram at a speed of from 20 to 30 strokes per minute. These two tools are produced in a great variety of shapes, giving a corresponding wide range of work.

Edge Forming and Flanging

For the forming and flanging of edges of sheet metal, special types of machines have been developed. One of these machines is a mechanical adaptation of the hand-beating technique, and will deliver from 250 to 500 blows per minute from a brake-head tool striking upwards against a holding-down tool, the total angle of this motion being controlled by a handwheel.

DEEP-DRAWING PRESS

For the mass production of shaped components in light alloys, use may be made of a deep-drawing press. For small work a single-action press may be employed, wherein a blank holder is operated either by spring pressure or by pneumatic means; while for larger work, or where mass production is necessary, double-action presses with cam or mechanical linkage movement of the blank holder may be used.

In general, crank presses are not so efficient as hydraulic presses, particularly for the drawing of the Duralumin-type of alloys, for these are very sensitive to variations in drawing speed, and may be fractured by the initial velocity of the

blow. The risk of fracture in this way is minimised with the hydraulic press, since the drawing pressure may be applied gradually, thus giving the metal time to flow. Hydraulic pressure may also be accurately controlled and stopped entirely when a specific pressure on the punch has been attained.

A number of factors decide the power and size of a press for deep-drawing operations, such as the class of metal being handled, thickness and shape of the work, and diameter of the blank. Hydraulic cupping and drawing presses may vary in capacity from about 50 to 1,000 tons or more, with strokes varying from 24 in. to 72 in.

With a specific press, draws of varying lengths can be made in sequence, the stroke being adjustable to the depth of the draw. Fig. 4 shows a double-crank press which has ample area of bed and slide faces and height from bed to slide. These features accommodate deep-drawing tools as used by electrical engineers, motor-car-body makers, and general sheet-metal workers. The full width between the sides is available for both top and bottom tools, by means of a special arrangement of the slide adjusting strips.

Air-cushion Equipment

This type of press when fitted with an air cushion is suitable for comparatively shallow raising operations, such as inverted drawing procedure, for which the die is mounted on the slide and the forming punch on the bed of the press. The pressure plate which holds the periphery of the blank during the operation is actuated by the air-cushion equipment. The steel bolster plate shown is removable, and is bored and bushed for a large number of pressure pins, which transmit the pressure of the air cushion to the dies.

Top extractor gear is fitted for removing stampings from the top die when necessary. A high-speed clutch is connected

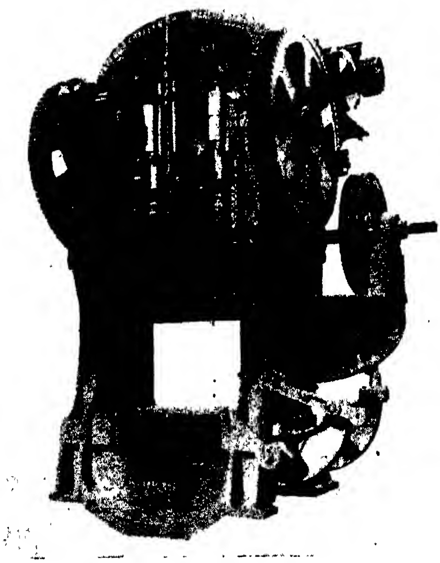


FIG. 4.—DOUBLE-CRANK PRESS

This press is capable of accommodating deep-drawing tools as used by motor-car-body makers and general sheet-metal workers. (*Taylor & Challen, Ltd.*)

to the driving shaft, which runs in roller bearings. Starting is by hand lever, the press automatically stopping at the top of each stroke. The slide is under control at any point of a stroke, for such purposes as tool setting, by means of an emergency lever. Adjustment to the height of the slide is quickly done through the medium of an electric motor.

Power Consumption

In general, the power used in drawing aluminium alloys and other light metals is appreciably less than that expended with steel and other relatively hard metals. Due to features inherent in light alloys, the drawing of them has to follow certain basic principles which are broadly as follows. The light alloy sheet must be allowed to flow as freely as possible. Drag of the metal, due to localised thickening of the walls of the drawn blank, may be obviated by easing the clearance of the tools in the region where thickening occurs, and by the utilisation of shaped blanks designed to even up the flow of metal into the region of high stress in the throat of the die.

While the pressure-plate loading should be sufficient to prevent wrinkling, it should be kept to a minimum; wrinkles may be caused by incorrect tool design or insufficient pressure-plate loading. Since the alloys are sensitive to the radius of the drawing die and also to the punch, if the radius of the latter is too small, the metal is liable to tear; and when too large the punch tends to pierce the sheet instead of allowing it to fill over the radius.

With the object of overcoming these problems, dies may be designed with a 45° bevel with suitably radiused corners. As the light alloys, such as aluminium alloys, have a high co-efficient of surface friction, the tools employed should have a very smooth surface and polish in the direction of flow, so as to lessen the risk of failure of the work by cracking, dragging, or tensional rupture. As abrasive particles have a high effect on such alloys, the work should be kept clear of them.

Use of Lubricants

Types of lubricant used in deep drawing vary with the amount of reduction per draw, tool material, die radii, and the thickness of metal. Normally, the greater the draw, the sharper the radii, and the thicker the metal, the heavier the lubricant required. For heavy reduction a lubricant consisting of 3 parts paraffin to 1 of tallow, by weight, may be used; while for lighter draws mineral oils are commonly employed.

A heavier lubricant is normally used with low-carbon or cast-iron tools, because these tend to induce scratching to a greater extent than dies made from hardened tool steel. If wood tools are used, the lubricant should be free from water, as this expands the wood, and a dry mineral jelly is commonly used. Other lubricants which have been successfully applied consist of wax or soap with a volatile solvent.

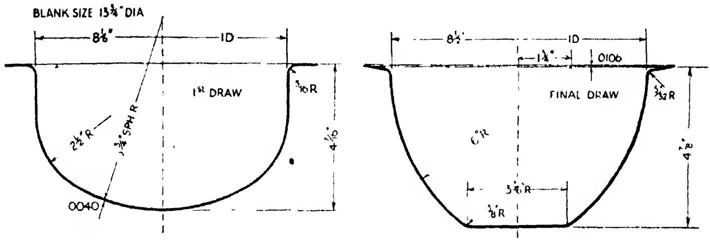


FIG. 5.—DETAILS OF THE FIRST AND FINAL OPERATIONS FOR DRAWING A BOWL SHAPE IN LIGHT-ALLOY METAL (*Aluminium Development Association*)

Drawn Contours

The contour of drawn articles may be classed as hemispherical, rectangular, cylindrical, and irregular. With relatively thin metal which tends to wrinkle during the final draw, the production of hemispherical shapes may present difficulty. The problem may be the presence of excess metal after the initial draw, or when the piece is formed in one single operation, there may be an incorrect ratio of blank thickness to inside diameter of the finished shell.

In general, the tendency to wrinkle may be minimised by seeing that the necessary quantity of metal is brought into position for the final draw during the initial draw stage. Wrinkling may also be avoided by making certain that the ratio of inside diameter to metal thickness is below 200 : 1. Fig. 5 gives details of the first and final operations for drawing a bowl shape in light alloy metal.

When drawing rectangular shapes—in order to avoid wrinkling or splitting—it is necessary to control the metal at the corners, for these points are where the greatest thickening of metal occurs. The problem of thickening is overcome by taking suitable precautions. For example, the drawn radii at the corners should be made slightly in excess of those at the sides and ends, the different radii being blended gradually one into the other. This technique overcomes resistance to flow caused by thickening of the metal. In order to give clearance between the blank holder and the die face, to allow for increasing thickness, the face of the blank holder should be hollowed out. This clearance should be virtually equal to increase in thickness, because if it is excessive, radial backing will occur at the corners.

Since excess metal increases difficulties in drawing, as little metal as is practicable should be used in the design of the blanks. The developed blanks and typical first and final shells for a rectangular pan are seen in Fig. 6.

As the metal thickens uniformly in cylindrical shells, it is not necessary to make allowances in the tools. Irrespective of the shape concerned, the extent to which sheet can be drawn in one operation varies with the nature of the alloy and its strain-hardening properties. To avoid excessive pressures and risk of splitting, each draw must be correspondingly reduced, due to the cumulative effect of work-hardening.

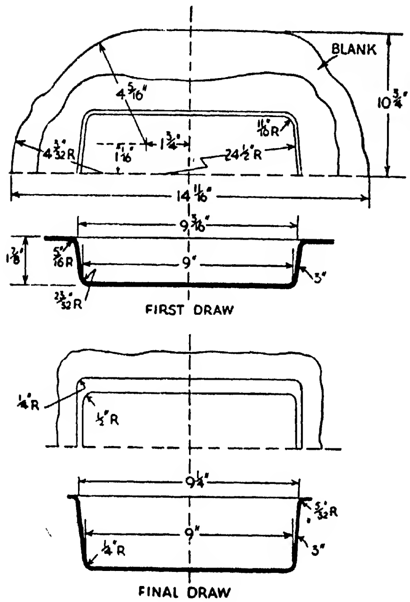


FIG. 6.—DIAGRAM OF THE DEVELOPED BLANKS AND TYPICAL FIRST AND FINAL SHEETS FOR A RECTANGULAR PAN (*Aluminium Development Association*)

PRESSING OPERATIONS

An alternative method of forming metal to the desired shape is that of pressing, as distinct from the drawing technique just described. One branch of pressing technique is that of coining, or embossing, a process used in the production of coins, medals, and similar pieces of metal.

Coining or Embossing

Coining consists essentially of the direct compression of the metal between a punch and a die in a suitable press. Metals used in this process are always in a relatively soft condition, because both malleability and ductility are necessary. To apply the great pressure which this work requires, a powerful toggle action is employed which actuates a long slide in which the top die is held. The joints of the toggle mechanism are equipped with steelings of special hardened steel, and are of ample dimensions to withstand the great pressure exerted in embossing or coining. The steelings at each joint are a set consisting of a roller and two dishes, or concave pieces, which receive the roller, and are themselves held in the levers or other members of the mechanism. A crankshaft at the back actuates the main toggle lever.

Presses used for Coining

Typical coining presses are shown in Figs. 7 and 8. In this type of press the hardened steelings which take the pressure on the toggle joints are of large size, and to ensure maximum life they are provided with automatic means of oil or grease lubrication, special oil seals to retain the lubricant, and an automatic rotating mechanism to ensure equal wear round the circumference of the roller members.

The slide works in very long guides of special type, lined with bronze gibs, and is raised by special balancing gear to avoid lateral stresses. The chief reciprocating parts of the toggle mechanism are spring compensated. A well-established feed and extractor mechanism is used, while an automatic hopper feed may also be fitted. A patent anti-clash device, which stops the press when

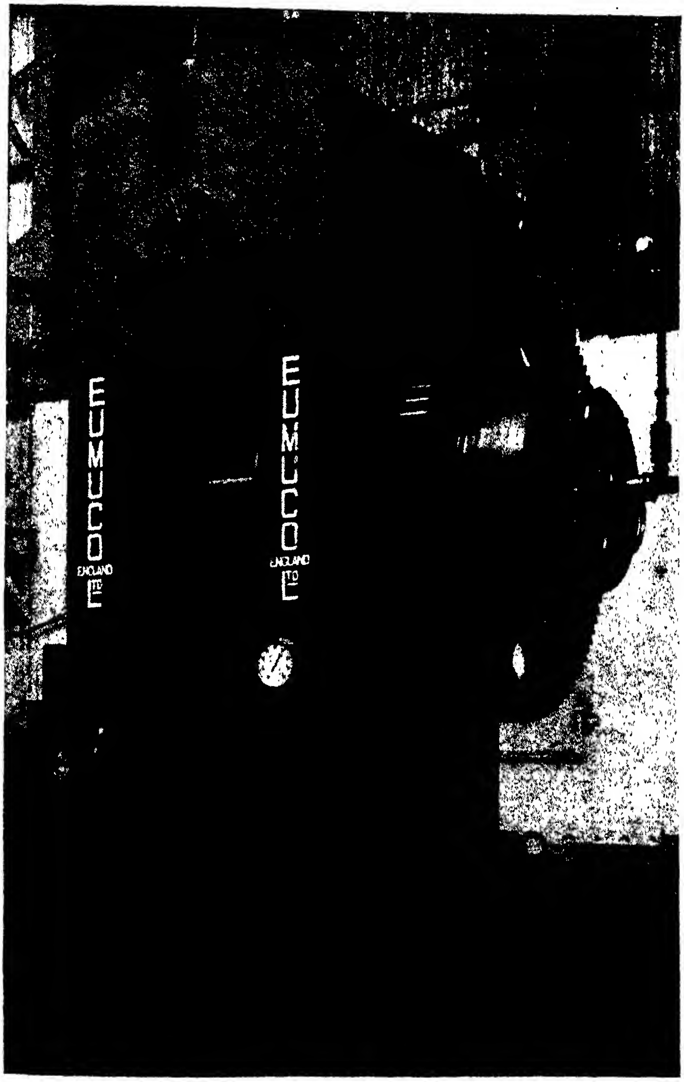


FIG. 7.—1,500-TON COINING PRESS (*Eumuco* (*England*), *Ltd.*)

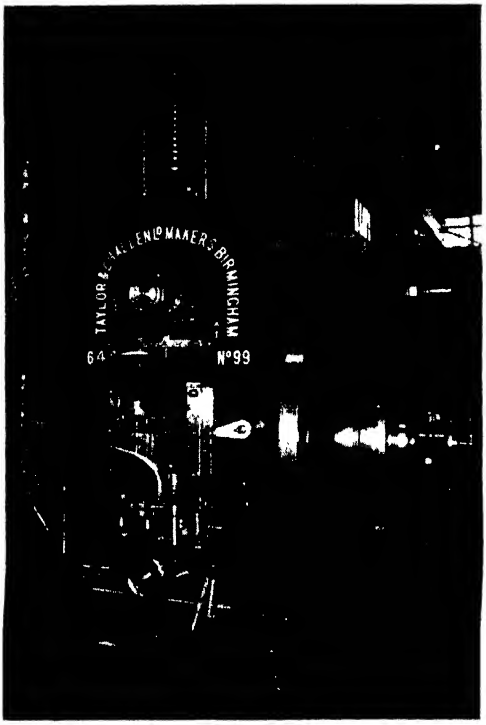


FIG. 8.—A TYPICAL EXAMPLE OF A PRESS FOR COINING OR EMBOSSING

It incorporates a patent anti-clash device which stops the press when no blanks remain in the feeder. (*Taylor & Challen, Ltd.*)

no blanks remain in the feeder, is fitted. This press will coin aluminium alloy coins up to $1\frac{1}{2}$ in. diameter; with harder metals the maximum diameter may be slightly less.

In presses for this purpose the frame is generally a one-piece casting of special iron, with a heavy front section to take the direct load. The crankshaft has a key clutch of special design, and the clutch-actuating lever also operates the automatic crankshaft brake through a special connection which permits the full speed of the press to be attained gradually.

The usual drive is by belt on to fast and loose pulleys, and the belt-shifting lever also actuates a brake on the flywheel. The feeding mechanism consists of a pair of finger levers, which have a double motion, consisting partly of a back and forward sliding action, and partly of an opening and closing action. The fingers take the blank from the base of the hopper tube into which it is fed, and place it on the lower die in position ready for striking.

Dies for Coining Presses

Both dies on such machines are made with adjustments in all directions horizontally to their correct location above the collar; but one die, usually the top one, has also a spherical seating. Owing to this feature, adjustment by "favouring" the die, or tilting it, can be made; so that extra pressure can be applied on one side of a coin, as is often necessary with some designs. Both

dies are held in their correct final position by four setpins, while adjustment of the pressure is carried out through three wedges.

The lowest of these is first set to give the approximate correct pressure, the small wedge just below the die block is then set to give the correct amount of lift of the bottom die through the collar, to extract the finished coin. Final adjustment of the pressure required is obtained by adjusting the upper wedge, which is first put in its outermost position. Extraction of the coin is carried out by cams on the feed mechanism.

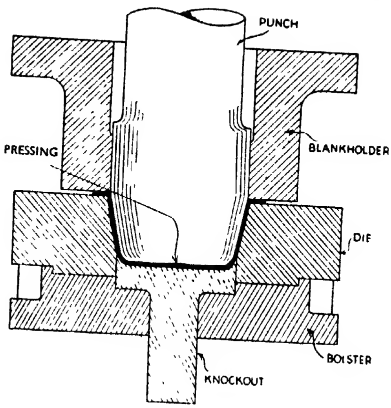


FIG. 9.—DETAILS OF GENERAL TOOL ASSEMBLY FOR THE MASS PRODUCTION OF MANY TYPES OF PRESSED WORK IN LIGHT-METAL ALLOYS

(*Aluminium Development Association*)

For the mass production of other types of pressed work consisting of the light metal alloys, the dies used are normally made of hardened tool steel, the bottom die being lubricated, with tallow for heavy gauge material, or a mixture of machine oil and paraffin for lighter work.

The general assembly of the tools for such pressing operations is seen in Fig. 9, from which it will be noted that the knockout covers a relatively large area of the work, to avoid marking or other damage when being ejected.

Method of Overcoming "Springback"

In operations of this character what is known as "springback" may be encountered—particularly with alloys of the Duralumin class—wherein the pressed article springs back out of the designed shape. With alloys having this characteristic the difficulty is overcome by modifying the method of pressing.

When the pressing has been taken almost to full depth under conditions of easy flow of metal through the blank holders, any further slip is restricted by readjusting the blank holder pressure; the punch then completes its stroke. By this means the amount of stretching necessary to minimise springback is obtained. In the case of aluminium alloys, springback may also be reduced by solution heat-treating the work immediately before the final forming operation.

Punch and Die Radii

The minimum permissible punch and die radii is influenced by several factors, such as class of alloy and type of press, and is best determined directly on the job under a given set of conditions. In such forming operations the material should conform closely to the profile of the tool, so that the risk of forming to a more obtuse radius than that intended is avoided. Two types of bend are

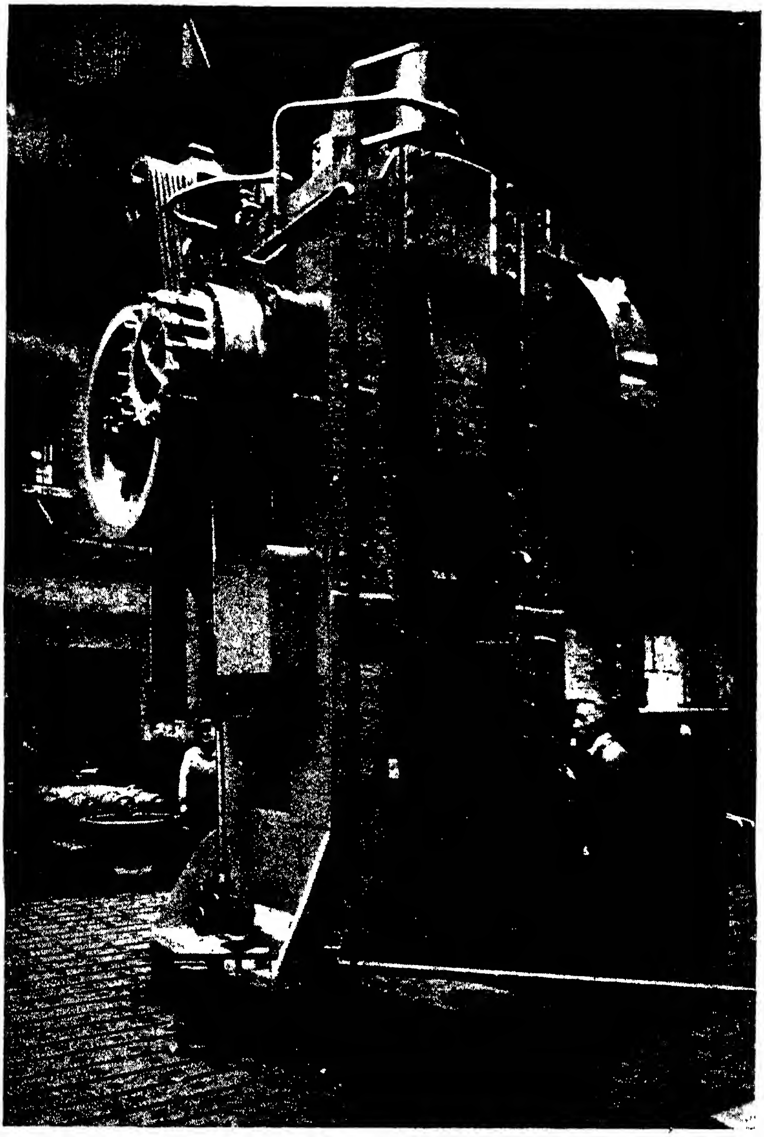


FIG. 10.—FRONT VIEW OF THE EUMUCO "MAXIMA" 1,000-TON HIGH-SPEED FORGING PRESS (*Eumuco (England), Ltd.*)

seen in Fig. 11, and it is obvious that a bend such as in (*A*) will not be as strong as the one in (*B*), formed with a rounded corner.

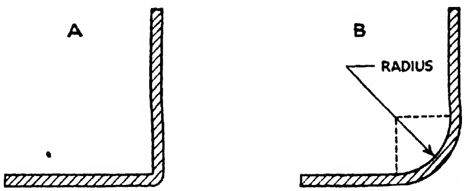


FIG. 11.—A POSSIBLE ERROR IN FORMING OPERATIONS

In *A* the angle is too sharp and is not so strong as in *B*, which latter represents a correctly radiused corner.

High-speed Press Forging

The press forging method is chiefly confined to the production of comparatively simple and symmetrical forgings. In this method the squeezed pressure in a vertical direction builds up to a maximum at the end of the stroke as it does on the operation of the horizontal forging machine. Whilst the latter performs its work in the horizontal plane on a bar, the forging press operates in the vertical plane on billets cut to proper size and heated to forging temperature. The billet is placed in the bottom die and is squeezed by the ram of the press into the various cavities of the dies. Multiple-impression dies are therefore usually employed for this class of work, including trimming and calibrating. Although on numerous parts, especially round-shaped components, insert dies may be used.

The mechanical press forging method exercises a slow squeeze pressure instead of the blow of a hammer. Press forgings are produced by applying the pressure upon a billet of metal which forces it to fill the cavities of closed impression dies which forms the metal into the shape required. The method is suitable for steel forgings and non-ferrous forgings.

As the dies on a forging press do not come into contact with each other during operation, they can be of smaller area than those used on hammers. Also, to remove the forging from the die at the end of a stroke, powerful ejectors are provided for both top and bottom dies on the press. This considerably reduces the draft required in the die.

A high-speed forging press of 1,000 tons capacity is shown in Fig. 10.

FORMING BY DROP STAMP

The drop stamp is essentially a mechanical panel beater, and is used for handling work which cannot be economically put through a power press, owing to the expense of press tools, such as forming tank ends, ducts and curved panels. Certain deep-drawn shapes, which were until recent years produced only by hand methods, are now fabricated from light-alloy sheet by the drop-stamp method. While some forms of work may be shaped by one single blow in the drop stamp, more complicated work requires a series of blows of varying intensity. To save the use of expensive dies for work which cannot be formed in one operation, forming may be done in stages, using plywood pressure plates or rings, which latter are removed one at a time until the desired shape is obtained.

The drop stamp is also used for eliminating wrinkles from work that has been partly formed in a power press.

Rope-operated Types

The drop stamp may be operated either by ropes or by compressed air and ropes, the latter being, in general, more efficient. In the rope-controlled machine the punch is fitted to a heavy slide, or tup, moving vertically, and is controlled by several turns of rope on a motor-driven friction drum. When the operator pulls the free ends of the rope, the friction is increased and the rope is wound up by the drum. According to the intensity of blow required, the operator slackens his pull on the rope at a given point, thus allowing the wound-up punch to drop on the work beneath.

Compressed-air-operated Drop Stamps

The compressed-air-operated machine is more easily controlled, pressure is more rapid and flexible, and the mechanism is more sensitive. This equipment has an oscillating rotating shaft carrying a drum, which rotates when air is admitted through a control valve to a cylinder, thus drawing up the lifting ropes attached to the tup. When the valve is moved to the exhaust position, the tup is released and falls freely by gravity, so that the length of stroke and intensity of blow are more easily controlled—and impose less fatigue on the operator—than is the case with the rope-operated machine. The air pressure used is normally around 100 lb. per square inch, and by means of a series of stops on the control mechanism blows of uniform intensity from a given height may be made, which arrangement lessens the skill required to operate the machine.

Drop-stamp machines are made in a variety of sizes, ranging from a working area of 30 × 24 in. with a 36-in. stroke, to 156 × 60 in. with a 60-in. stroke, the blows varying from one to three per minute according to the size of the machine.

Drop-stamp Tool Design

The tools employed are normally soft-metal castings, dies being made from zinc alloys and punches from antimonial lead. When the useful life of such tools is ended they can be melted down and recast. As considerable disruptive forces are present in the soft-metal dies, alloys for making these are chosen so that advantage can be taken of low temperatures combined with adequate strength. Ample metal must be in the base and sides to enable it to withstand the maximum blow. These soft-metal dies can be produced in low-temperature foundries in a small fraction of the time needed to make a similar shape in steel.

In the U.S.A. wide use is made of punches of plastic material, using these with zinc-alloy dies. The Americans claim that these plastic punches—because of their greater flexibility—will form many parts more consistently than the antimonial lead punches. The punches are thermoplastic, so that they can be reshaped by heating, several types of synthetic resins being available for punch fabrication. As the noise created by the impact with a plastic punch in the machine is much less than it is with a metal one, the machine is less tiring to operate.

Several methods are available for fixing the punch to the machine. For example, while the punch is being cast, cores may be suspended in the top of the casting boxes to provide holes for the mounting of bolts, which are secured in a jig suspended in the cored holes. The surrounding metal is made fluid by the local application of heat, thus filling the holes with molten metal, which holds the bolts in position when it sets.

In Fig. 12 is outlined an alternative method of fixing a punch. In this arrangement the retaining plate and tapped tube are cast in the punch with the top of the tube about $\frac{1}{2}$ in. below the top of the punch, so leaving clearance for machining. The method facilitates the replacement of any broken studs or bolts, while possible difficulty in mounting the punch on the tup is overcome by positioning the bolts accurately in the punch. In fixing, the punch is placed in the die, the tup lowered, and the punch aligned with the fixing holes.

Any discrepancy in fitting, where the part has not been machined, may be eliminated from the lead castings by chipping hammers, or by portable grinders in the case of zinc-alloy castings; the punch is then bolted to the tup and raised slightly. Final adjustment is accomplished by placing strips of metal of the gauge to be formed in suitable positions in the die; the bolts on the anvil are loosened, the punch lowered for centralising, and the bolts holding the die made secure. Where necessary, extra security may be had by screwing a series of bolts in the anvil and surrounding the die with molten lead as a key.

Use of Pressure Plates

In the light-alloy industry many shapes may be successfully formed by the drop-stamp machine with the use of suitable pressure plates or draw rings. These may be made either of plywood or of rubber, while the bottom plate may be of Duralumin-type alloy sheet of about 10 S.W.G. and routed out to the appropriate shape. This plate should be solution-treated where the design of the die face is contoured or of uneven shape, and while the plate is still soft it should be placed on the die. The tup is then lowered into position and allowed to stand until the plate has acquired the shape of the tool face and has hardened sufficiently to retain it. A metal plate used in this way prevents the draw rings from adhering to the sheet metal during drawing. Plywood used for the remaining plates or rings is normally $\frac{3}{16}$–$\frac{1}{2}$ in. in thickness. These pieces, when routed to shape, cover the flange of the work as it rests on the top surface of the die, as is seen in Fig. 13, which shows the use of plywood plates or rings on an air-operated drop stamp.

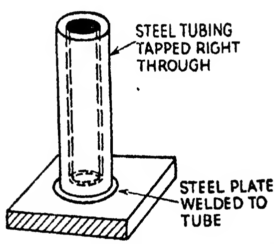


FIG. 12.—ONE METHOD OF FIXING A PUNCH IN THE DROP-STAMP MACHINE

It facilitates the replacement of any broken studs or bolts.

One or more of the rings may be removed after each blow of the punch, a final heavy blow serving to set the pressing when the last

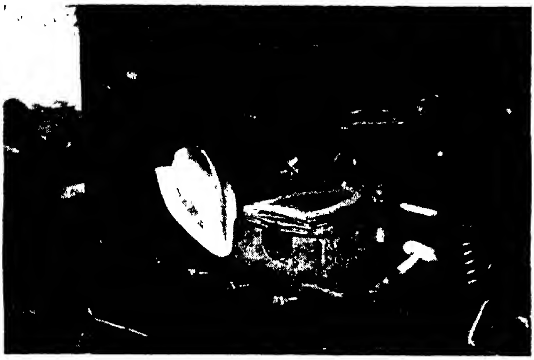


FIG. 13.—ILLUSTRATING THE USE OF PLYWOOD PLATES, OR RINGS, ON AN AIR-OPERATED DROP STAMP (*Alfred Herbert, Ltd.*)

ring has been removed. The pressure plates used in this way have the object of drawing the metal in from the sides, so keeping the skirt appreciably free from wrinkles. Fig. 14 depicts a method of producing three pressings simultaneously on a 96 × 48-in. air-operated stamp, using pressure rings. This method can be adopted where the work handled is not large. Three dies are cast and mounted together in one machine, so saving appreciable time by reducing the number of drop stamps needed. In this technique the punch may be of zinc-base alloy, both die and punch being lubricated with a thin mineral oil, the forming sequence being somewhat as follows.

The blank is placed over the first die and struck a light blow; it is next placed over the second die and struck one light and one medium blow; then transferred to the third die, where it receives one light and one heavy blow. In the case of aluminium alloys, the work is then removed from the machine, heat treated at 480–500° C. in a salt bath for 30 min., and quenched in water. To eliminate any distortion, it is then restruck on the third die,

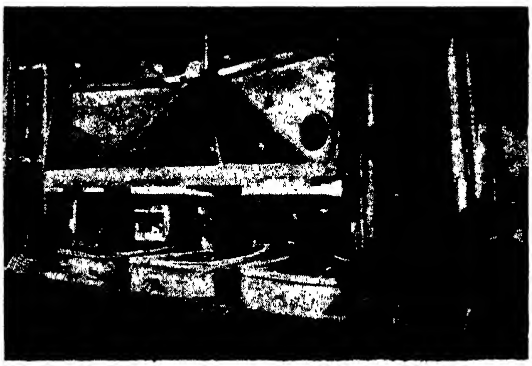


FIG. 14.—PRODUCING THREE PRESSINGS SIMULTANEOUSLY ON A 96 × 48-IN. AIR-OPERATED STAMP USING PRESSURE RINGS (*Alfred Herbert, Ltd.*)

receiving a final trim to reduce the flange to the size required.

In handling difficult pressings, with corners and radiused edges, the use of rubber pads $\frac{3}{4}$ in. or 1 in. thick may eliminate wrinkling by placing the pads where it is likely to occur, the pads being successively removed before the final setting blow is struck. Figs. 15, 16, and 17 show three stages in the use of rubber pads to eliminate wrinkling in the production of a double curvature.

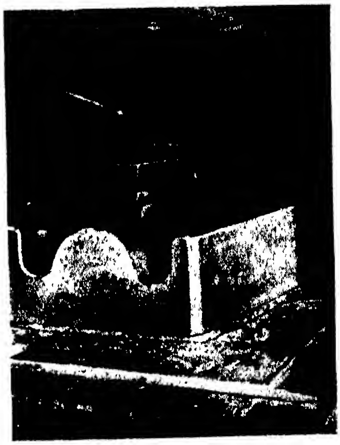


FIG. 15.—DOUBLE CURVATURE PRODUCTION WITH THE AID OF RUBBER PADS, FULL PADDING IN POSITION

(*Alfred Herbert, Ltd.*)

Shrinking

Sometimes work has to be shrunk in the centre in order to form it, as in parts in a compound curve. Shrinking in this way may be accomplished by placing a pyramid of rubber pieces of $\frac{1}{2}$-in. thickness, of varying sizes, on the sheet metal in the die, the biggest rubber piece being against the work. This latter piece should practically cover the centre area of the alloy, the remaining pieces of rubber being piled on top in ever-decreasing sizes. When a blow is struck by the punch at the head of the pyramid, the impact is more pronounced on the small area of the part in the centre, the difference in pressure serving to prevent wrinkles forming. As each piece of rubber is removed, the area of impact from the blow progressively increases, and the development of wrinkles is thus curtailed.

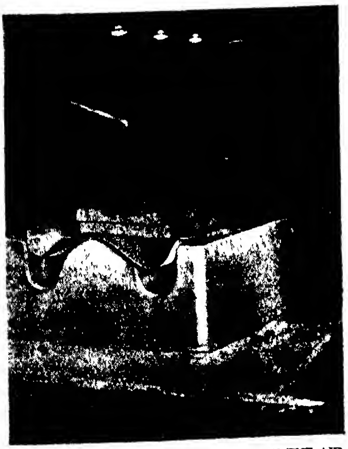


FIG. 16.—DOUBLE CURVATURE WITH THE AID OF RUBBER PADS, PADDING PARTLY REMOVED

(*Alfred Herbert, Ltd.*)

Types of Alloys

The process of pressing, drawing, or stamping metal is essentially a cold-forming operation, and it is an advantage for the operator of the presses and other machines to understand what changes occur in the metal during these cold-working processes.

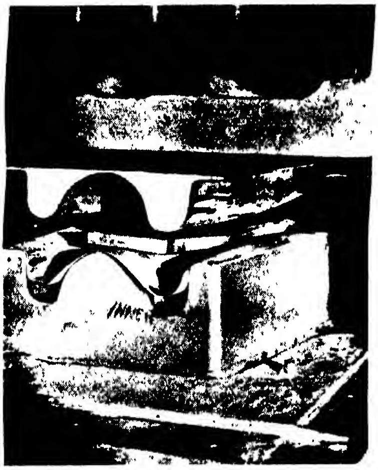


FIG. 17.—DOUBLE CURVATURE WITH THE AID OF RUBBER PADS, LAST PAD IN POSITION BEFORE FINAL BLOW IS STRUCK

(*Alfred Herbert, Ltd.*)

The act of working the metal in the machines just described increases its hardness and tensile strength, but lowers its ductility. In many cases the component produced in the presses has to be put through a form of heat treatment before the pressing operations can be completed, so as to modify the physical properties of the work. The press operator in some engineering shops is also responsible for the heat-treatment of the work he is producing. Much of this work consists of the various types of aluminium alloys. These can be divided into two main classes, non-heat-treatable and heat-treatable alloys. The first class of alloy attains its maximum physical properties by cold work alone, while the latter class is both cold worked and heat treated.

Metal which is in the non-heat-treatable stage is normally put through the presses either in a soft or semi-hard condition, and it obtains its increased strength through the pressing operations. With some types of metal, however, an annealing process is necessary at an intermediate stage in the pressing operations.

Heat Treatment

After heat treating an alloy of the natural ageing type, it attains its maximum strength when allowed to remain at a normal temperature within four or five days. The pressing operations are commonly carried out on such metal almost immediately after the heat treatment to avoid age-hardening.

The process of artificial ageing, or precipitation treatment, consists essentially of heating the quenched alloy to between 130° and 200° C., the heating period varying with the properties of the alloy. Heat treatment is normally carried out in three successive steps: (1) heating the metal at the appropriate temperature for the required period; (2) quenching; (3) ageing, either at normal temperatures or by low-temperature reheating. What has become known as "solution treatment" comprises (1) and (2). The methods of heating the metal involve the use of either a molten salt bath or a forced-air circulation furnace. The salt bath is the more flexible of the two, for it will accommodate work in any form or shape, but the air furnace does not deal so conveniently with such mixed loads of work; with the air furnace, however, there is no risk of corrosion of the work by the chemicals of the salt bath.

A. E. W.

HYDRAULIC PRESSES

THE machines covered by this description, which embraces any press operating by means of a liquid under pressure, are built in a wide range of types and sizes, for many different duties, and may have one or more hydraulic cylinders arranged horizontally, vertically, or in a combination of both.

Any survey in an article of this nature must therefore be confined to a review of the basic principles involved, together with descriptions of certain selected types sufficient to give a general view of the subject, and consideration of the various points of detail design which more directly concern the press builder than the press user. This limitation has been kept in mind throughout the following pages.

Basic Principles

As the name implies, hydraulic presses were originally operated solely by water, but the term has now been extended to cover the many types using oil as the pressure medium.

In all cases, however, the basic principle remains the same as that used by Joseph Bramah, to whom the first practicable hydraulic press is attributed, and who died in 1814 at the age of sixty-six. His patent application, dated 1795, for "Obtaining and Applying Motive Power," is still in existence.

This principle is based upon the theory that water is incompressible, and that any force exerted upon a unit of surface area in one direction will be reproduced equally upon each similar unit of surface area in any other direction.

Actually this is not strictly true, as water is compressible to the extent of approximately ½ per cent. of its original volume under a pressure of 2,000 lb./sq. in. and the compressibility of oil is some 50 per cent. greater, but this does not materially affect operations apart from a slight loss of overall efficiency.

It can thus be seen that if two cylinders, each containing a movable plunger, are connected together by means of a pipe and the system is filled with water or oil, any load per unit area impressed upon the plunger in one cylinder will be transmitted by means of the liquid to the plunger in the other cylinder. The total load upon each plunger will be proportional to its cross-sectional area, if the compressibility of the liquid is ignored, and if it is assumed that no losses occur due to leakage around the moving plungers. This latter is prevented by suitable packing, which does, however, still further reduce the efficiency of the system by introducing a small amount of friction.

In the arrangement just mentioned, the plunger in the first cylinder, to which the load is applied, represents the pump or other source of hydraulic power,

and the second plunger to which the load is transmitted represents the hydraulic press. This will exert a load equal to the area of the plunger multiplied by the unit pressure of the liquid, less any losses such as those due to friction, and if the areas of the two plungers are suitably proportioned, any desired increase of power can be obtained.

Thus, if a represents the area of the first plunger in square inches, and f represents the load applied to it in pounds, the pressure on the fluid will be $\frac{f}{a}$ lb./sq. in. If again the area of the second and larger plunger is represented by A, the force F exerted by this plunger will be $\frac{f}{a} \times A$ lb. or $F = f \times \frac{A}{a}$, that is, the force exerted by the second plunger will exceed the force applied to the first plunger in direct proportion to the ratio between the areas of the two rams. This is assuming 100 per cent. efficiency, but in practice it is, of course, necessary to make a suitable allowance for the losses already mentioned. It should also be noted that as the work got out can in no case exceed the work put in, the distance moved by the first plunger must exceed that moved by the second plunger in the same ratio of $\frac{A}{a}$, and the total effect is that a smaller force exerted over a greater distance is converted into a larger force exerted over a smaller distance.

Press Construction

The actual hydraulic press itself consists of one or more cylinders, each containing a plunger, to which liquid under pressure is admitted.

The plunger may be either a plain single-acting ram or a double-acting piston, the latter giving a power proportional to the full area of the piston head in one direction, and proportional to the area of the head less the area of the piston rod in the other direction.

A variation of the plain ram is the stepped or differential ram which extends through both ends of the cylinders and gives a power in one direction only, which is due to the liquid pressure acting upon the annular area of the shoulder or step.

PACKINGS

Packings must be fitted where the ram passes through the ends of the cylinders, to prevent leakage, and also to the piston head when this is adopted.

Grease Packing

One of the cheapest forms of packing still used for comparatively low pressures is known as "grease packing," and consists of hemp or similar material plaited into a square section and impregnated with grease. Several turns are fitted into the cylinder mouth, which is bored out to receive them, and the packing is compressed sufficiently to prevent leakage by a gland plate which is screwed up tightly by means of bolts or studs on the cylinder end.

Leather and Synthetic Packings

The grease packing does, however, cause a great deal of friction, resulting in loss of power and heavy wear on the ram, and from this point of view the well-known U leather, illustrated in Fig. 1, gives much better results. As the name implies, it consists of a leather ring of U section, which is fitted in a groove around the cylinder mouth with the closed end outwards.

Liquid leaking past the ram enters the U, and forces the two lips outwards, one against the cylinder wall and one against the ram, thus preventing further egress, and one great advantage is that as the sealing action is due solely to the liquid pressure, the friction is kept to the minimum necessary to avoid leakage and is automatically adjusted to the pressure in the cylinder.

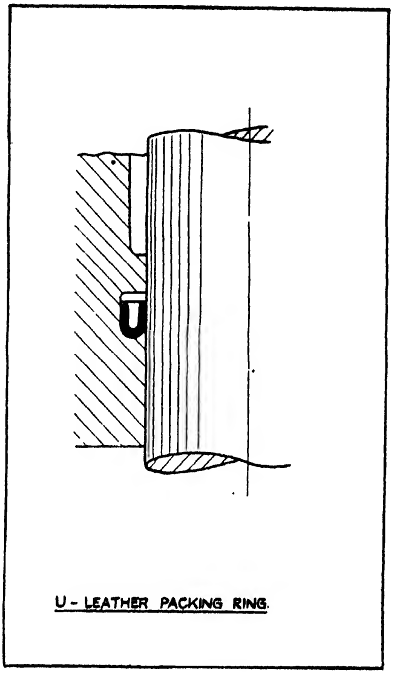


FIG. 1.—SELF-ADJUSTING TYPE OF LEATHER PACKING RING

Such rings have one great disadvantage, however, in that owing to the nature of the material they are apt to fail without warning. This invariably occurs during pressing, and is a serious matter in the case of a large forging press where the ingot must be returned to the furnace whilst a replacement is fitted. The leather must also be specially treated when oil is used as the working fluid, and for these reasons fabric or synthetic rings incorporating the same lip principle are now generally used as shown in Figs. 2 and 3. There are many reliable makes and types, and they can be fitted either as single uncut rings, which must be slipped on over the end of the ram, or in multiple rings which may be cut to facilitate fitting and are then arranged with the cuts or joints staggered.

In all cases they must be held in place by a gland plate, and bronze or gunmetal gland rings and neck rings are usually fitted adjacent to the packing rings to form guides for the ram.

Similar packings are used for piston heads, and must be fitted with the lips outwards in the case of single lip packings, but in cases where oil is used as the pressure medium, it is now customary to fit piston rings on the piston heads

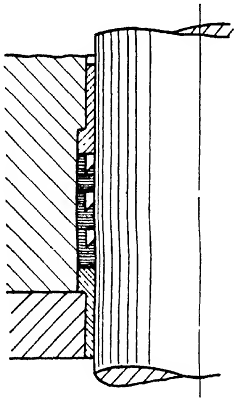


FIG. 2.—EXAMPLE OF FABRIC RAM PACKING RINGS

(Fig. 4), similar to but smaller than those used on steam pistons, and these give excellent results.

PRESSES FOR PRODUCTION PURPOSES

The characteristics of the various types of hydraulic presses in present-day use for production purposes are given in the following paragraphs. Those designed for workshop operation and forgings are dealt with later in this article.

The Simple Upstroke Press

Probably the simplest form of hydraulic press consists of a vertical cylinder formed in the base with the cylinder mouth uppermost and containing a piston or ram. The fixed or top head of the press which opposes the pressing load is maintained at a fixed height above the base by means of columns or tie rods reduced in diameter at the ends to form an abutment shoulder and fitted with nuts. These columns are often four in number, but presses have been built with two, three, or even six or eight columns.

The moving head, often known as the crosshead, is mounted on the upper end of the ram, and may be guided if necessary upon the columns. In the simplest presses of this type the cylinder is fitted with a plain ram which performs the pressing stroke only, and after pressing the moving head falls by gravity when the pressure liquid is released or "exhausted" from the cylinder.

If a quicker or more definite withdrawal is required, the cylinder can be fitted with a piston which will exert a downward force proportional to the area of the annulus between the piston head and rod, or alternatively, the plain ram can be retained and two smaller cylinders and rams can be fitted, one at each side of the press, to give the required downward action. If fitted on the top head of the press, these rams are known as "push-backs," and act directly upon the moving head; but if fitted at the sides of the base; they become "pull-backs," and must draw down the moving head by means of lower crossheads and tie rods.

An alternative to this makes use of differential cylinders, in which case the lower crossheads and tie rods are dispensed with, and the upper ends of the rams, which are smaller in diameter than the lower ends, are connected directly to the moving head by means of a turned-down portion and a nut. A disadvantage of this method is that glands and packings are required at each end of these pull-back cylinders, with the consequent increased need of maintenance and liability to leakage.

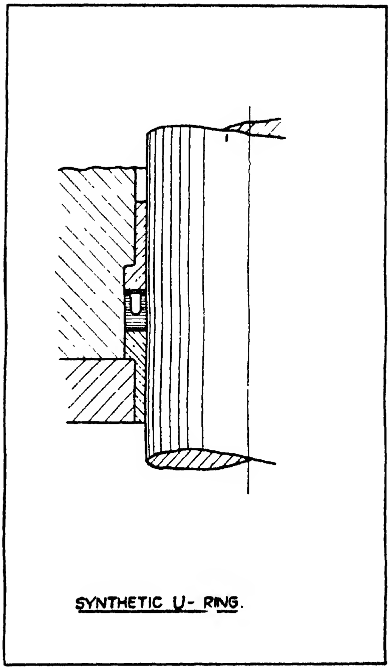


FIG. 3.—U-TYPE PACKING RING IN SYNTHETIC COMPOUND

It is obvious that with a press of this type, the whole of the upward stroke must be performed by the pressure liquid, and this is uneconomical in cases where any considerable amount of idle stroke is required before the actual pressing commences. For this reason, the upper head is sometimes made adjustable for vertical height upon the columns, and is locked in position by nuts. Another method is to use a separate service of low-pressure liquid for the idle stroke, cutting this off and changing over to the high-pressure liquid for the pressing stroke only by means of suitable valves.

The same result can also be achieved by fitting pistons in the side cylinders. The moving head is then lifted by pressure liquid operating on these pistons, and, at the same time, liquid from an overhead tank flows into and fills the main cylinder through a prefilling valve. As soon as the resistance to the presshead movement increases sufficiently, due to the commencement of pressing, the pressure liquid is admitted either automatically or by hand to the main cylinder, and the full press power is exerted. Withdrawal is carried out in the usual way by admitting pressure to the upper sides of the side cylinder pistons, and the liquid in the main cylinder is returned back to the tank.

In certain cases where the upward idle stroke of the press must be carried out very quickly, the overhead tank is replaced by a pressure vessel, which contains air under pressure above the filling-up liquid, but as the air pressure will oppose the return of this liquid to the pressure vessel when the moving head

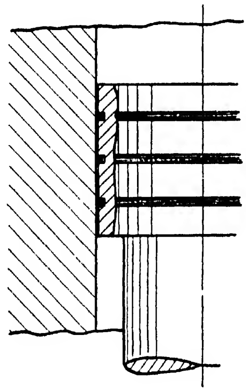


FIG. 4.—PISTON-RING TYPE OF PACKING

falls, a suitably increased power must be arranged for the side cylinders.

A large upstroke press can be seen in Fig. 5, which shows a multi-platen press for making laminated sheets up to 7 ft. long by 3 ft. wide. The press has two cylinders, giving a maximum power of 1,650 tons, and the platens are arranged for steam heating and water cooling.

Downstroke Presses

These are an inverted form of the upstroke press, one advantage being that the lower pressing table is stationary and the upper table descends. The opposite is the case with the upstroke press, where the variable working height of the lower table can interfere with the handling of the products.

One or more lifting cylinders, or a piston-type main ram, are necessary to raise the moving head, and if side cylinders are used, they may have either plain or differential rams as already described for the upstroke presses. If the cylinders are fitted to the press base, plain rams acting vertically upwards can be attached directly to the moving head of the press, as also can differential rams if the cylinders are mounted on the press head. Plain rams in this position, or in a single cylinder located over the main cylinder, require upper crossheads which are attached by tie rods to the moving head, and this type can be seen in Fig. 6, which shows a battery of four 25-ton moulding presses. The differential ram type of lifting cylinder is used on the 1,000-ton plate-flattening press shown in Fig. 7.

When a piston type of main ram is adopted, the annular area under the piston head between the cylinder bore and the circumference of the piston rod gives the lifting power, and although pistons were not regarded with much favour at one time owing to the possibility of leakage past the head, modern types of packing have done much to restore them to favour. This is particularly true when oil is used as the hydraulic medium, and in such cases pistons fitted with piston rings are now widely used.

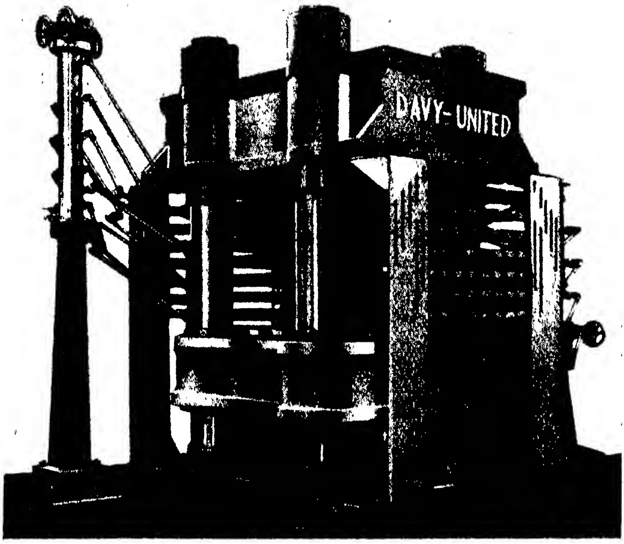


FIG. 5.—UPSTROKE HYDRAULIC PRESS FOR THE MANUFACTURE OF LAMINATED SHEETS
Maximum power 1,650 tons.

FIG. 6.—FOUR 25-TON MOULDING PRESSES
Downstroke type.

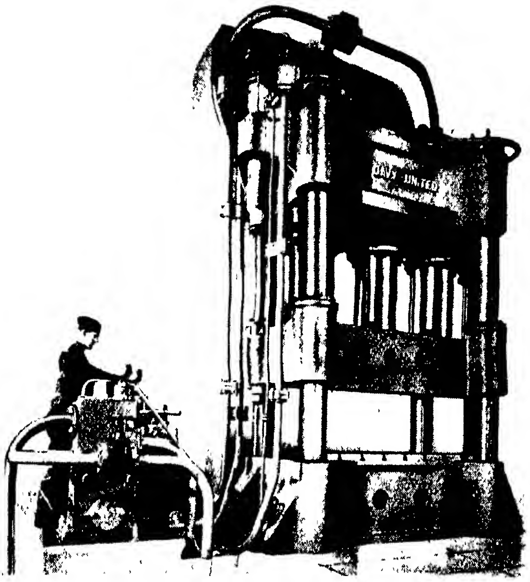


FIG. 7. — 1,000-TON FLATTENING PRESS

Downstroke type, with differential ram-lifting cylinders.

Whichever type of lifting arrangement is employed, "constant-pressure" operation can be adopted if the whole of the downstroke of the press is carried out by pressure liquid. In this system the lifting cylinders, or the lifting area of the main piston when this type is in use, are supplied directly from the hydraulic service without the interposition of a control valve, and the upward load is overcome by the downward thrust of the main ram when pressure is admitted to the main cylinder. The liquid from the side cylinders, or from the underside of the main piston, is forced back into the service line, where it augments the flow to the main cylinder until such time as the valve controlling this cylinder is again opened to exhaust. Pressure is then released from this cylinder, and the press head is immediately raised by the constant pressure under the lifting rams or piston.

In many cases, however, it is more economical to use low-pressure water or oil from a tank on the press head to fill up the main cylinder during the idle falling stroke of the press, and to admit the high-pressure liquid only during the actual pressing stroke. It is then necessary to control the lifting cylinders or piston by means of a valve, and to exhaust them during the falling stroke, which is carried out by the force of gravity, together with any liquid head due to the height of the filling tank, the latter being often augmented in the case of high-speed presses by introducing air pressure into the filling tank. This then becomes a pressure vessel, which must be suitably designed, and it can be mounted at

floor level if required, as if an air pressure of say 60 lb./sq. in. is used, the additional pressure obtained by mounting the tank on the press head is negligible.

Such a system can be taken a step farther by having a separate low-pressure service to carry out the idle stroke, and it is then again possible to employ constant-pressure lifting cylinders if the low-pressure service gives enough power on the main ram to overcome them. Two separate services, however, naturally introduce complications, and are only justified in special circumstances.

Frame-type Presses

Earlier in this article, when describing the upstroke press, it was stated that the top and bottom fixed members of the press were connected together by columns, but both upstroke and downstroke presses are built in which the two fixed members and the connecting ties all form part of one solid frame. The frame may be either cast in iron or steel, or fabricated from steel plates and sections, and a cast frame upstroke press is shown in Fig. 8. This is a 460-ton coining press, in which this particular construction is adopted to give maximum rigidity and to ensure as far as possible that the working faces are parallel to each other, and the same reasoning applies to the 750-ton downstroke press shown in Fig. 9, which is used in the manufacture of abrasive wheels.

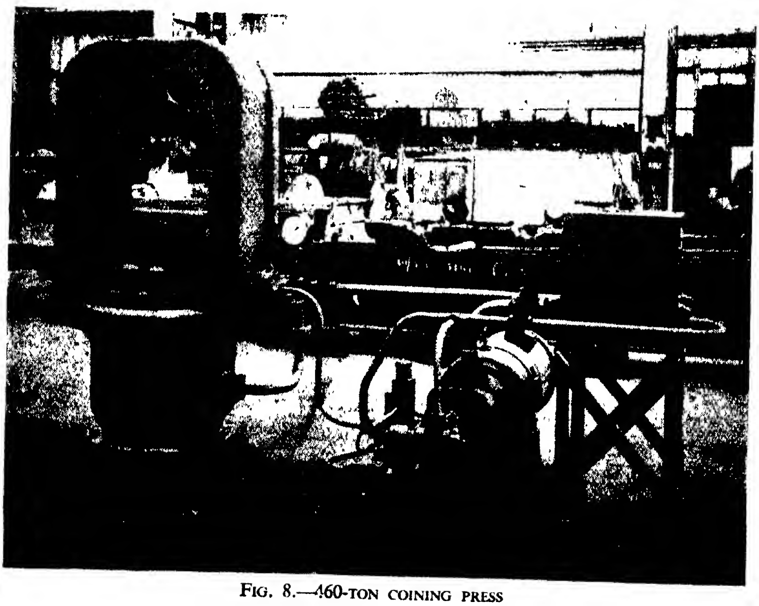


FIG. 8.—460-TON COINING PRESS
Upstroke-frame type, with individual pump.

FIG. 9.—750-TON ABRASIVE WHEEL PRESS
Downstroke-frame type.

Fabricated frames are often used on high-speed deep-drawing presses, the side members and the moving heads being fitted with either V or flat guides, or a combination of both, which are adjustable to take up wear and to enable accurate alignment to be maintained between the top and bottom tools.

Another type of frame press has individual top and bottom heads separated by hollow side members through which pass tie rods to hold the whole assembly together. The tie rods may, if necessary, be pre-stressed by tightening them up when heated, thus putting them under a stress greater than that which will be imposed by the normal working load as a prevention against slackening off of the nuts during operation.

Here again guide faces can be arranged upon the side members to maintain alignment of the moving head.

Horizontal Presses

It is often an advantage from an operational point of view to arrange a press horizontally, but the basic principles still remain the same as in the types already described. A typical example is an extrusion press for the production of cored solder, which has two columns, and larger presses, usually having three columns, are used for the extrusion of light alloy or brass sections, bars, and tubes. In these, the billet is loaded into a cradle, and is then pushed into the container by an extrusion ram fixed to the moving crosshead of the press. Further movement of the crosshead forces the billet through a suitable die, and the material is extruded in the desired shape on 'to a table fitted with rollers, where it is either sawn or sheared to any required length.

Such extrusion presses are built in powers ranging up to 8,000 tons, and in these cases and in that of the small solder press, the column type is adopted, as it allows greater accessibility than would a solid frame press.

One point which must receive particular attention in a horizontal press is the greater tendency to loss of alignment due to the uni-directional wear caused by the weight of the moving parts.

This weight acts vertically downwards, allowing the extrusion ram to become out of line with the container, and this is enhanced by the unavoidable overhanging of the ram from the moving head; and in all but the smallest horizontal extrusion presses additional guiding surfaces are fitted below to crosshead. Suitable means of adjustment are required to take up the wear as it occurs,

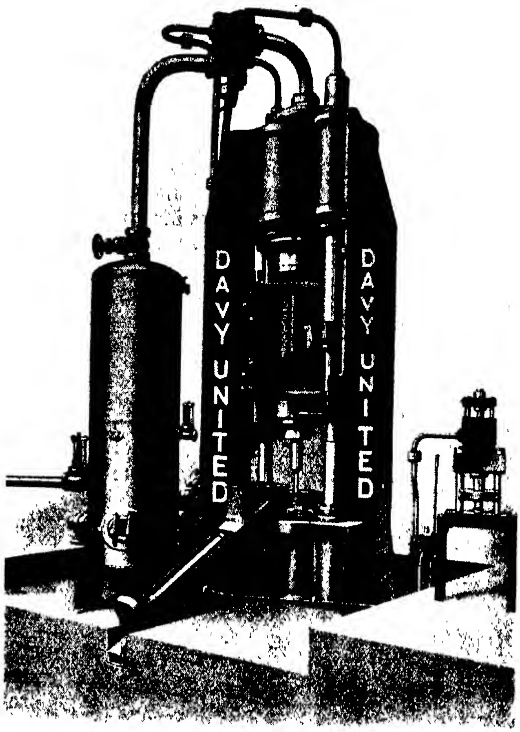


FIG. 10. — 750-TON EXTRUSION PRESS
Vertical-frame type.

and it is necessary to make provision for the expansion of the crosshead due to the heat generated by the extrusion process.

It is therefore sometimes argued that a vertical press requires less attention to maintain alignment, and although it is not strictly relevant to this particular section, such a press is shown in Fig. 10. This has a power of 750 tons, and it will be seen that it is of the solid frame design. It is used for the extrusion of non-ferrous alloys.

PRESSES FOR WORKSHOP OPERATIONS

So far, apart from the plate-flattening press, shown in Fig. 7, the presses illustrated and described have all been intended for actual production purposes, but many other types are built for workshop operations, such as the forcing of wheels on to shafts and the pressing of laminations or core plates on to the rotors or the stators of electric motors.

Straightening presses may also be considered as coming into this category, together with the many types of forming, bending, and flanging presses, but space limitations must rule out all but the briefest references to these.

Armature Presses

The two presses shown in Fig. 11 are, however, worthy of more than a passing glance, as they offer an inexpensive but effective design for pressing laminations on to armatures and similar duties, replacing the screw presses often used for these purposes. The illustration shows them after assembly but before delivery to site, and it will be seen that they are of the vertical upstroke type with gravity return, and are fabricated from steel plate and sections. The inner vertical members are the two columns, and two cylinders are used, pressing being carried out between the moving crosshead mounted upon the rams and the adjustable head higher up on the columns. The vertical distance between these two main members, known as the "daylight" of the press, can be varied to suit the particular work in hand by raising or lowering the adjustable head into any one of four positions and locating it there by split collars above it which fit into the necked-down portions of the columns.

The two outer vertical members are tubes forming guides for the balance weights which hold up the adjustable head against the split locating collars, and which are attached to the head by wire ropes passing over pulleys at the top of the press.

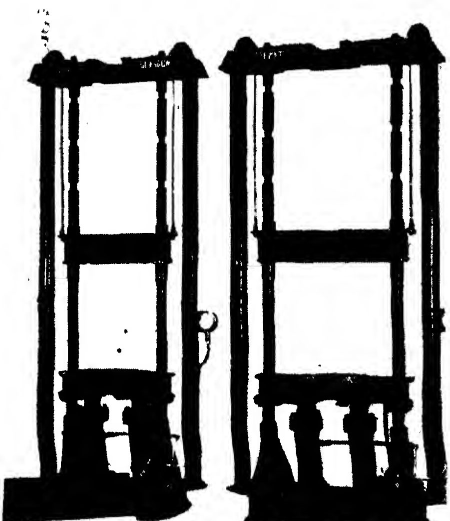


FIG. 11.—TWO 15-TON ARMATURE PRESSES
Upstroke two-column type.

The moving and adjustable heads are shaped to receive the overhanging shaft portions of the assembly which is to be pressed, and the fixed upper head tying the tops of the columns together is similarly shaped. A hole is also provided in the base member of the press for the same purpose.

Forcing Presses

Presses for forcing locomotive wheels on to axles are arranged horizontally and are of much greater power than the small upstroke presses just described. These again usually have two

columns with a similar method of location for the adjustable head, but the balance weights are, of course, omitted. The press heads are again shaped to receive the overhanging axle journals and the adjustable head is mounted on wheels or rollers to help in moving it into its various positions.

Straightening Presses

Both horizontal and vertical designs of presses are used for straightening bars or shafts, but the principle is the same in each case, the bar or shaft which is to be corrected being placed against two supports and the load being exerted at some intermediate point.

Fig. 12 shows two 120-ton vertical presses with extended bases which carry the supporting blocks. The bases must be capable of withstanding the bending moment due to application of the load at the maximum distance from the centre line of the main ram, without the help of any support from the foundations, thus making the press self-contained as regards loading. On these particular presses the supporting blocks carried on the press bases were fitted with spring-mounted rollers for ease of movement, the springs deflecting when the press load was applied and allowing the blocks to seat firmly on the base.

Troughing and Plate-bending Presses

Presses used for making sections for coal conveyors, and those employed for bending the chassis frames of heavy commercial vehicles, are usually vertical, and may be either upstroking or downstroking. More than four columns are often used when the press has to handle long products, and they are then arranged in pairs, with one main cylinder between each pair of columns, giving in effect two or more two-column presses connected together by the top and bottom pressing heads.

Additional cylinders may also be required for clamping purposes, and this also applies to dishing presses used for forming

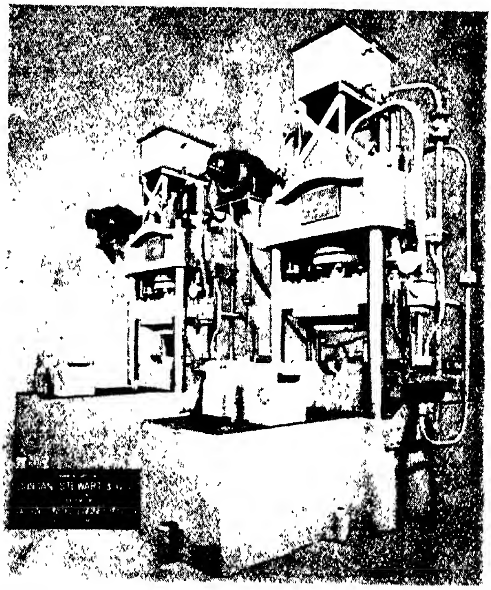


FIG. 12.—TWO 120-TON STRAIGHTENING PRESSES WITH INDIVIDUAL PUMPS

the dished ends of boilers and pressure vessels. These latter presses are often vertical upstroking, with large circular pressing tables and heads.

Another very useful type of press is the horizontal plate-bending press, which has large vertical rollers fitted to the heads, giving three-point bending.

The larger presses of this type are capable of bending steel plate of $\frac{3}{16}$-in. thickness to a width of 80 in. These dimensions imply rigid construction, and "brakes" are made in either steel or cast iron, reinforced against distortion by steel bars shrunk in hot.

J. G. F.

RUBBER DIE PRESSES

The use of the rubber die press for forming light-alloy sheet, introduced to industry in 1935, is proving particularly advantageous in the production of a wide variety of shapes and sizes of components that do not warrant the use of more expensive hardened-steel dies or tools of a permanent nature. During the Second World War the rubber die press was applied to the making of many types of aircraft components, and in these post-war years it is being increasingly used in the production of radio and television parts, pressings for the electrical industry, toys, and similar articles. The rubber die press enables such operations as forming, blanking, piercing, shearing, flanging and drawing to be carried out with simple and inexpensive tools.

The essential components of this type of press include a thick rubber pad inside a steel container, the latter having sufficient strength to withstand the maximum pressure exerted by the press platen, the rubber having a thickness about two-thirds the depth of the container. On the surface of the platen are placed the dies, which may be of hardwood, zinc or steel, the work to be formed being placed on the dies and positioned by location pegs.

In operation, the movement of the platen by hydraulic pressure forces the dies and the work against the rubber pad, and the latter, as it is compressed, compels the metal to shear, bend or form to the shape of the die. In such a case it is the frictional properties of the rubber—as distinct from the ability of the rubber to flow—that are the main feature in forming work by this method and the pressure obtainable is limited by the shear strength of the rubber. The action of the rubber under compression is seen in the diagram (Fig. 13).

Pressure Range

For such a process both high and low pressures are used, the low-pressure presses covering a range of about 500–2,600 tons, with an average platen pressure of about 0·5 ton per square inch. On these low-pressure presses a considerable amount of work on sheet from 14 to 20 S.W.G. is produced, while the rubber used may be either solid or built up from 1-in. laminations of 50–55 Shore hardness.

The higher power presses utilise pressures of from 5,000 to 10,000 tons or even more, giving an average platen pressure of about 1·5 tons per square inch.

In the high-power press the rubber pad may be as large as 9 ft. × 4 ft. × 10 in., being housed in a steel container and vulcanised to a steel plate having tapered holes to secure a firm anchorage.

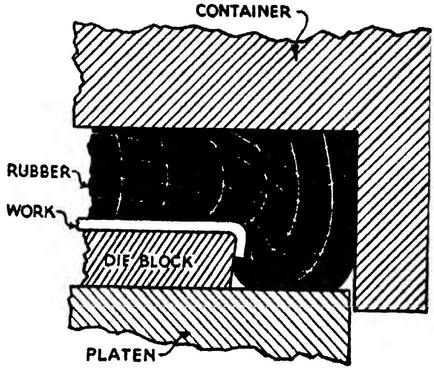


FIG. 13.—DIAGRAM ILLUSTRATING THE ACTION OF RUBBER WHEN UNDER COMPRESSION IN THE RUBBER DIE PRESS

Constructional Details

Examples of presses of this type having different powers are seen in Figs. 14, 15, and 16. It will be noted that the simplicity of this process makes possible the employment of semi-skilled female labour.

In these presses the platen, which is mounted on the cross-head of the cylinders, moves upwards into contact with the rubber through the action of a series of hydraulic cylinders distributing the pressure evenly over the entire area. The forming dies are grouped on the platen, the dies being at least 2 in. apart.

There may be two loading tables—moving on ball-bearing rollers—to each press, these tables being run direct on to the platen. The rollers on the platen are spring-loaded, and as soon as the rubber is engaged the load is transferred from the rollers to the platen, the tables being moved in and out of the platen through a friction drive.

From a control panel, seen on the left of the press in Fig. 16, the press is controlled electrically, one lever operating the press movement and two levers controlling a safety door at each end of the platen. These levers are interconnected, so that the press cannot operate with the doors open.

In the high-power press with its platen pressure of 1·5 tons per square inch, the pressure is sufficient to bend 10 S.W.G. heat-treated aluminium alloy sheet, but a big proportion of work can be formed at the lower platen pressure of about 0·7 ton per square inch.

The low-power press may be made from contoured mild-steel plates of about 1½ in. thickness, and in these units the power cylinders and driving mechanism are appreciably lighter than those in the bigger presses. In the low-power machine there may be four loading tables, two at each side of the press, the platens running into position, and then being power-fed on to the cross-head of the cylinder in turn. The pressure can be arrested at any point of the stroke required, which facilitates the forming of intricate work. With a press of 2,650 tons capacity, the cycle time is 5 minutes for a complete operation, each table being processed.

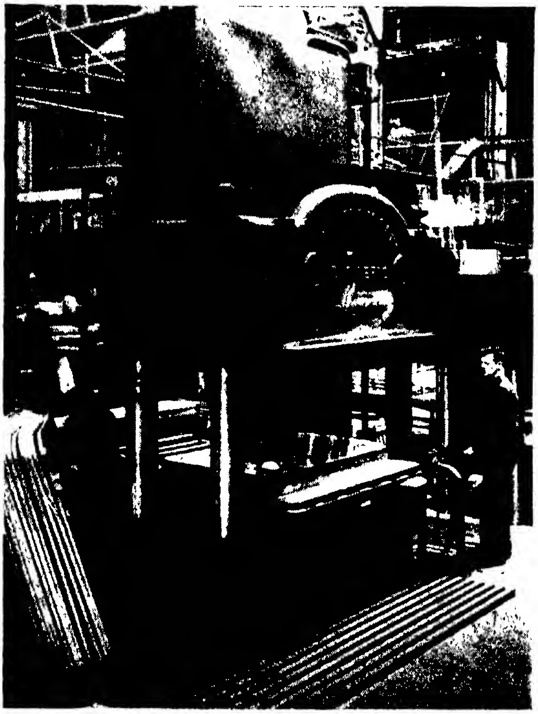


FIG. 14.—A MODERN TYPE OF RUBBER DIE PRESS OF 785 TONS

There is an average pressure of from 0·5–0·7 ton per square inch on the platen.

(*John Shaw & Sons (Salford), Ltd.*)

Die Construction

Dies and tools for use in the rubber die press are made to the inside contour of the formed work, and many of them are designed to combine both shearing and forming in one operation. For this process parts can be formed by external pressure that cannot conveniently be done by internal pressure; so that forming occurs over a projection rather than into a recess.

For example, if work is to be bent through an angle of 90°, and external pressure be applied with a forming block, as in Fig. 17, a relatively small pressure only is needed, due to the uniform distribution of the load, and a close fit will be obtained at the apex (*A*), irrespective of a big or little radius at that point. But a bend obtained as in (*B*) entails the application of localised pressure during the final forming, and it is difficult to obtain a sharp corner at (*B*) without an additional operation.

For the production of only a few hundred components, dies of seasoned hardwood or red fibre may be used, and, when metal faced, such dies will produce several thousand components, such as in operations involving the

FIG. 15.—AN EXAMPLE OF THE HEAVIER TYPE OF RUBBER DIE PRESS, OF 5,340 TONS, GIVING A PLATEN PRESSURE OF AROUND 1·5 TONS PER SQUARE INCH (*John Shaw & Sons* (*Salford*), *Ltd.*)

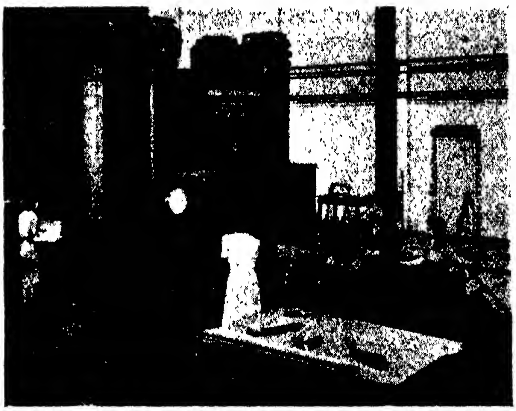
raising or forming of flanges, stiffening ribs, lightening holes, and bulkhead panels. Temporary dies for such work may also be made from Canadian birch veneers impregnated with phenol-formaldehyde resin. This material has a compressive strength of about 40,000 lb. per square inch with a Brinell hardness of 45, and can be readily machined.

Forming tools of a permanent nature may be made from mild steel plate,

FIG. 16.—THE SIMPLICITY OF OPERATION OF THE RUBBER DIE PRESS MAKES POSSIBLE THE EMPLOYMENT OF SEMI-SKILLED FEMALE LABOUR

The press is entirely controlled electrically from the control panel on the left of the press

(*John Shaw & Sons* (*Salford*), *Ltd.*)



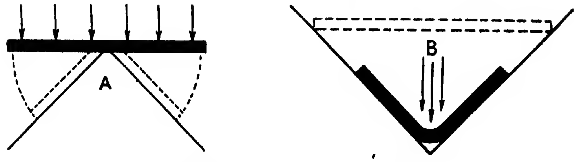


FIG. 17.—THE USE OF A FORMING BLOCK IN THE RUBBER DIE-PRESS TECHNIQUE
A forming a V-bend by external pressure; *B* forming a V-bend by internal pressure.
(*Aluminium Development Association*)

and they cost much less than hardened-steel dies. Where large components and high pressures are involved, the dies may be of cast iron, and the excessive weight of these can be reduced by recessing during casting.

However, a big proportion of the dies used in this sphere is composed of an alloy of 96 per cent. zinc, with 4 per cent. copper; or, alternatively, with zinc and small proportions of aluminium, copper, and magnesium. These alloys are relatively soft, and can be handled by pattern makers on ordinary wood-working machines, the larger sizes of dies being strengthened by using a 10 S.W.G. mild-steel bedplate. At pressures up to 0·7 ton per square inch on the platen such alloy dies have a very long life.

Choice of Rubber

While rubber compresses to only about 0·04 per cent. per 100 lb. per square inch, it displaces readily. Its Shore hardness may vary from 15 for very soft material up to about 100 for the so-called hard rubber, or ebonite. Thus, for making rubber dies, a wide range of material is available. In use, the displacement of a soft rubber may be too quick for pressure to be exerted at the required point and at the proper time, so impairing the flow of metal. On the other hand, a rubber that is too hard may displace too slowly, so that complete closure cannot be obtained, even at maximum pressure, and spaces remain due to the immobility of the rubber.

From practical experience it is known that a rubber with an elongation range of 350–650 per cent. is suitable for all work in this sphere, while for drawing operations a Shore hardness of from 50 to 60 is appropriate, and for forming and shearing from 65 to 80 Shore hardness is considered suitable.

A rubber tool should possess high resistance to abrasion, the property of recovering quickly after deformation, good ageing properties, and a tensile strength of at least 3,500 lb. per square inch. Using a suitable rubber it is possible to form 20,000 alloy components without any appreciable wear on the rubber surface. Damaged rubber surfaces may often be built up again by grinding away the worn surface, filling up with either a self-vulcanising, or a cold-vulcanising, rubber compound. The life of all rubbers is prolonged by keeping them clear of all oil and grease. For rubber lubrication a non-abrasive powder, such as french chalk or fine graphite, is used, the lubricant being dusted on the metal being formed before pressure is applied.

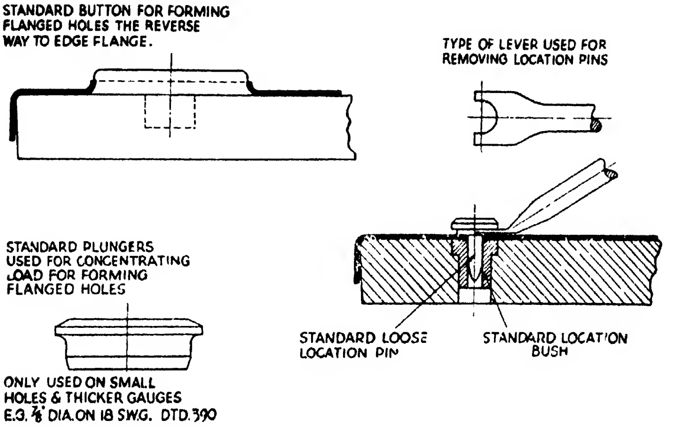


FIG. 18.—OUTLINES OF SOME TYPICAL STANDARD TOOLS FOR FLANGING OPERATIONS IN THE RUBBER DIE PRESS (*Aluminium Development Association*)

Rubber Die Press Technique

While with such operations as blanking and piercing in a power press shearing is due to the sudden impact of the applied force, with the rubber press the essential factor is pressure, and this has to be built up until it exceeds the resistance offered by the metal.

In the rubber press the critical pressure cannot be applied at a given point; it must be exerted over the whole area in contact with the rubber. Therefore, in blanking with the rubber press one must primarily consider the relation of the available hydraulic pressure to the surface area of the rubber pad and platen. On Duralumin-type alloy sheet of 20 S.W G., blanking by a rubber press may not be economic for small sizes of 2–3 in., for each part requires a marginal allowance of at least 1 in. There the ratio of scrap metal to size of blank is very high. But due to lower tool costs, the rubber press has an advantage over the power press for the cutting of a large number of different-shaped blanks simultaneously.

Some standard tools for flanging operations in the rubber press are outlined in Fig. 18. The blanks are positioned on formers with loose vocation pins of $\frac{3}{16}$ in. or $\frac{1}{4}$ in. diameter, the pins having recessed heads for easy withdrawal with a forked lever. Soft forming tools are normally fitted with steel location bushes, for constant withdrawal of the pins causes excessive wear on the composition tool. Location holes should preferably be positioned so that when the blank is reversed the holes do not mate with the bushes in the tools.

In Fig. 19 is outlined another method of forming flanges, wherein a blank locating block, resting on springs, enables the blanks to be correctly located. On top of the blank locating block and the part formed, a draw ring is placed,

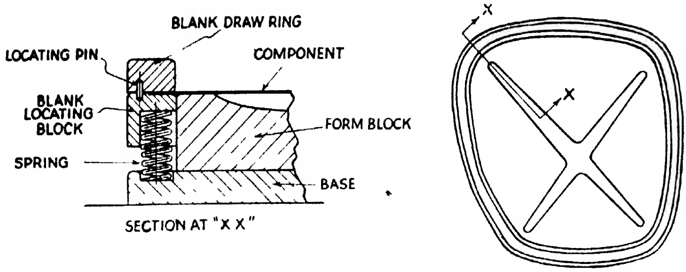


FIG. 19.—DIAGRAMMATIC ARRANGEMENT OF AN ALTERNATIVE METHOD OF FORMING FLANGES IN THE RUBBER DIE PRESS

the springs being compressed as the draw ring and locating block are forced down. When the load on the rubber pad is released, the locating block acts as an ejector, forcing the part off the tool.

The rubber press is capable of doing drawing operations on light metal alloys, provided the shape to be drawn comes within the limited technique permissible in this type of press. In such operations the drawing die is positioned on the platen and the blank placed between the die and rubber pad. A piece of 1-in. rubber sheet, large enough to cover the blank and cut to the shape of the blank to be drawn, is used as a pressure pad to control the flow of metal during deformation.

Pieces of rubber of 60–70 Shore hardness are placed over the blank to be deformed, then pressure is applied, thus causing the rubber to force the metal into the die. The pressure is next released, and other pieces of rubber added so as to extend the draw farther at the second stage. Each successive draw decreases in extent until the sheet finally touches the bottom of the die. With a well-annealed aluminium alloy, a 7¾-in. draw can be done in five stages.

A. E. W.

PRESSES FOR THE HOT FORGING OF METALS

This class includes some of the most powerful presses yet built and may be subdivided into two categories, one covering those intended for general forging duties, usually on steel, where, owing to the exigencies of the work, the pressing load may have to be applied at some distance to either side of the main centre line of the press, and the other including those used for forging between some form of dies, where the press load may be considered as being reasonably central.

In each category the vertical downstroking four-column type of press is almost invariably adopted, as the four columns give greater accessibility all round than does the frame type of press, and the vertical downstroke arrangement gives a fixed lower table upon which the work can be placed. An exception to the four-column type occurs, however, in the smaller sizes of general forging presses, where a C-type frame having an open gap in front is often used to facilitate the handling of awkward forgings.

General Forging Presses

Fig. 20.—6,000-ton forging press
Operated by two steam hydraulic intensifiers.
(*Beardmore & Co., Ltd.*)

These have been built in powers up to 15,000 tons, and must have a high speed of operation to enable as much work as possible to be done upon the ingot or forging in one heat. Pressing speeds are usually around 2–3 in. per second, with lifting and lowering speeds up to 12 in. per second, and allowance must be made in the design for the eccentric loading due to the out-of-centre forging already mentioned, which causes an overturning moment to be exerted on the moving crosshead that carries the top tool.

For this reason presses of 2,000-ton power and upwards are often built with two main cylinders located one at each side of a central guide stalk mounted on the moving crosshead. This guide stalk slides in a bush or guide cylinder in the upper fixed head of the press, and the moving head thus takes the form of an inverted T, which reduces the side load owing to the increased effective arm opposing the moment due to the eccentric load. The main rams are flexibly attached to the crosshead to avoid any side load being transferred to the cylinder glands and packings, and are thus free to perform only their true function of exerting pressure, as all guidance is confined to the crosshead guides and to the stalk. A 6,000-ton press of this type is shown in Fig. 20.

This design gives great rigidity, but is open to an objection when operating with fluid at one fixed pressure, as is the case when pumps and accumulators are used, in that the water demand during the pressing stroke is the same irrespective of the actual work being done. Thus a 6,000-ton press of this type will use a volume of pressure water capable of giving 6,000 tons power, even though the work which is being carried out requires a power of only 2,000 tons.

For this reason, an alternative design which replaces the central guide stalk by an additional cylinder, making three in all, is sometimes used. These three cylinders are arranged so that either the central cylinder only, the two outer cylinders only, or all three together, may be used, and both the water requirements and the power exerted vary proportionately.

Presses for Die Forging

These presses are much less liable to out-of-centre working, and when intended solely for one particular product may be simplified as regards the cylinder arrangements.

Fig. 21 shows a 6,000-ton press built for forging railway wheel blanks, which has one main cylinder only. The main ram is 55 in. diameter and exerts 3,000 tons when operating from a line pressure of 3,000 lb./sq. in.; and the power is increased to 6,000 tons for the final forming operation by means of a hydraulic intensifier. This press is fitted with two bottom anvils, one for roughing and one for finishing, mounted on a sliding table, so that either can be brought under the press when required, and arrangements for bringing in the appropriate top tool are also included. In addition, gripping fingers mounted below the moving crosshead can raise and suspend the wheel blank whilst bottom tools are being moved.

The hydraulic intensifier is perhaps worthy of note. The basic principle is that if the power of a ram in a larger cylinder at a lower pressure acts directly upon the ram of a smaller cylinder, the pressure in the lower cylinder will be increased in inverse proportion to the areas of the two rams. In this particular case, the larger cylinder receives water at 3,000 lb./sq. in. when the appropriate control valve is opened and the ram operates directly upon another ram rather less than half the area of the first, which is carried in a cylinder separately supplied with water.

The pressure on the water in the second cylinder is thus twice that in the first, namely, 6,000 lb./sq. in. after allowance has been made for losses due to friction and stretching of pipes, and this higher pressure water is fed into the main press cylinder from which the line pressure has been diverted.

This gives a press power of 6,000 tons for the final forming operation, and allows the use of a much smaller main cylinder than if the full 6,000 tons power was obtained directly from the 3,000 lb./sq. in. line. It also conserves pressure water in the earlier operations, where a power of 3,000 tons is adequate.

The prefilling vessel is a cylindrical steel vessel containing water with air above it under a pressure of 60 or 80 lb./sq. in. to give rapid prefilling of the main cylinder during the idle falling stroke.

Die forging presses for the forging of light alloys, particularly for aircraft work, have been built in this country up to 12,000 tons power, and there is one of 18,000 short tons power in the U.S.A., all being of the four-column design.

PUMPING EQUIPMENT

Any review of hydraulic presses is incomplete without some reference to the source of the hydraulic power which operates the press, and this must primarily be one or more of the many types of pump now available with or without the addition of an accumulator, or pressure storage vessel.

The pumping capacity must be sufficient to give the required speed of pressing, and if an overall efficiency of 85 per cent. is assumed, 0·4 horse-power per

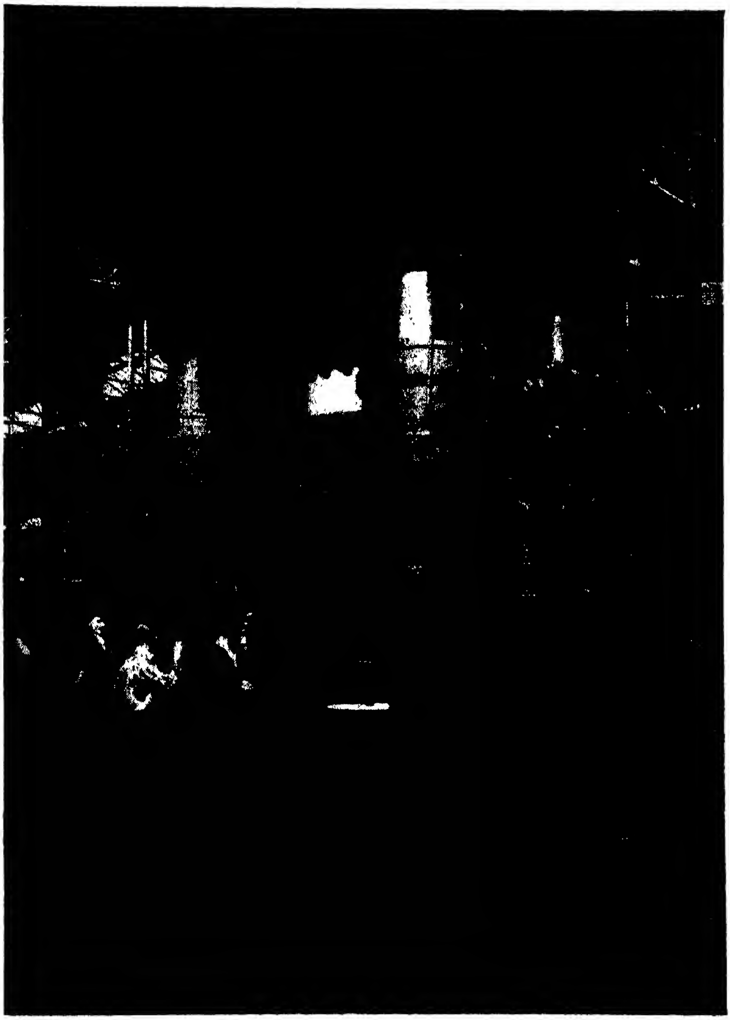


FIG. 21.—6,000-TON RAILWAY WHEEL FORGING PRESS
Operated from pump and accumulator service with hydraulic intensifier.
(*Steel, Peech & Tozer, Ltd.*)

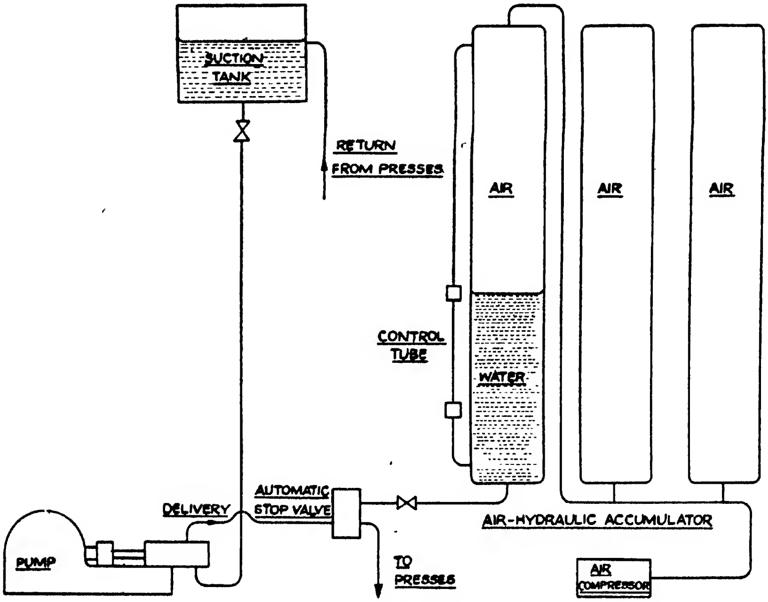


FIG. 22.—DIAGRAMMATIC ARRANGEMENT OF PUMP AND AIR-HYDRAULIC ACCUMULATOR

ton of press power will give a pressing speed of 1 in. per second. This figure is given as an approximate guide only, as higher overall efficiencies can be obtained from certain types of pump, but it does form a basis for calculations when the press is operated directly from the pump.

This arrangement, which is as old as the hydraulic press itself, has become increasingly popular with the advent of the neat and compact high-speed pumps now available. These are directly coupled to an electric motor, and the whole assembly, with a suitable tank, may be mounted adjacent to, or actually upon, the press as shown respectively in Figs. 8 and 12. Such pumps must use oil as the pressure medium, as they then become self-lubricating.

Much larger three-throw pumps, running more slowly and operating on water, have been used successfully for the direct driving of forging presses. The pump size must be adequate to cover the peak demands.

Accumulators

In general, however, when medium or large presses require either intermittent high-speed operation or long power strokes of varying speeds, the pump sizes become very large, and the electrical control gear to give variable speed becomes elaborate.

An alternative is then to interpose some form of storage vessel between the

pump and the press, thus creating a reservoir which will supply the peak demands of the press at any required speed compatible with the size of the pipes and valves, and which can be replenished by the pump during periods of little demand. The actual water requirements are thus averaged out on a time basis and a much smaller pumping capacity will be adequate.

Such a storage vessel is called an accumulator, and is also applicable when several presses have to be supplied from one central pumping plant.

The earlier accumulators consisted of a vertical cylinder and ram, loaded to the required pressure either by weights or by a tank filled with ballast, which was arranged to stop the pump or pumps when it reached the top of its stroke,

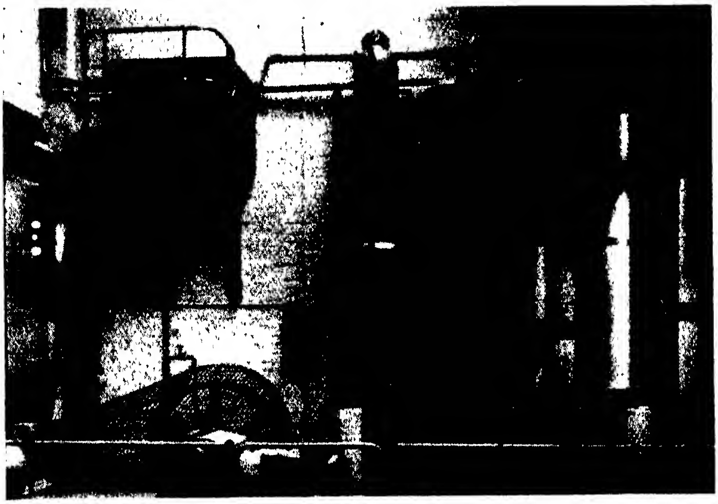


FIG. 23.—50-GALLON AIR-HYDRAULIC ACCUMULATOR, 1,150 LB./SQ. IN., WITH 25-F.P. PUMPS IN FOREGROUND (*Bruce Peebles, Ltd.*)

and was therefore fully charged with pressure water, and to restart the pumps when water was drawn off and the weights or ballast tank fell to some lower point of the stroke. This gave, and still gives, a straightforward arrangement, but owing to the heavy loading required to give the pressure necessary, which might be 250 tons or more for large accumulators, it was essential that expensive foundations should be provided and also that the falling speed should be kept to a low figure to reduce shock and water hammer in the pipes when the press valves were closed.

Air-hydraulic Accumulator

These difficulties are avoided in the more recent air-hydraulic accumulators, which consist of a series of pressure vessels containing water and air at the

required pressure (Fig. 22). The loading is then applied by the compressed air instead of by weight, there is no moving mass, and the air has a cushioning effect which tends to absorb any shocks.

The foundations can be reduced to those necessary to carry the weight of the pressure vessels together with the water and the compressed air, but one important point to note is that as the pressure of a gas is inversely proportional to its volume at constant temperature, the drawing off of a volume of water will allow an increase in the volume of air and a consequently reduced pressure. This reduction is usually confined to 10 per cent. of the nominal pressure by making the volume of compressed air equal to nine times the volume of usable water, and may be arranged as plus or minus 5 per cent. on the nominal figure.

The air is, of course, recompressed to the original figure when the water is returned to the accumulator, and air replacement is only necessary to make up leakage losses from pipe joints in the air system and from the slight amount of aeration of the water which takes place. An automatic valve closes down and prevents any further draw-off if there is any danger of an excessive demand exhausting the water in the accumulator and allowing the air to pass into the press system. Fig. 23 shows a 50-gallon accumulator of this type, operating at 1,150 lb./sq. in.

Steam-hydraulic Intensifiers

Another type of hydraulic power supply often used for the general forging presses is the steam-hydraulic intensifier, which gives a very flexible means of operation, but which is not now as popular as it was owing to the difficulties and expense of steam raising in comparatively small units. Where these difficulties can be overcome, however, it has proved to be very successful, and many examples are working most satisfactorily, giving press speeds on light rounding-up strokes which can probably not be equalled by any other method.

In principle it is similar to the hydraulic intensifier already described, but a large steam cylinder takes the place of the low-pressure hydraulic cylinder and acts upon a high-pressure hydraulic cylinder which is directly connected to the main cylinder of the press. A full stroke of the intensifier then gives an equivalent power stroke of the press, and the intensifier is virtually a single-ram steam-driven pump, making individual strokes which are reproduced proportionately in both speed and length by the press crosshead.

The press shown in Fig. 20 is operated by two such intensifiers, which can be used either singly or together.

The illustrations shown in Figs. 1–12 and 22 in this article are reproduced by permission of Davy & United Engineering Co., Ltd.

J. G. F.

GUARDS AND SAFETY DEVICES

PRESS GUARDS

ACCIDENTS between the tool and the die on power presses average just over two per working day throughout the year. The number is not large and, indeed, appears insignificant in comparison with the figures returned for road casualties. But the accidents with power presses differ from those met with in other activities, because they almost invariably result in permanent disablement.

Little can be done, even by expert surgical treatment, when a punch which deals with quarter-inch metal has come in contact with flesh and bone. That is why the subject of guards has closely engaged the authorities for many years, and probably more care and thought have been given to devising adequate safety measures for power presses than for any other machine in industry.

Despite the preference for the fixed type of guard expressed by the Factories Act (1937), the automatic principle has always strongly appealed to power-press users, and a large number of clever automatic guards have been introduced for these machines. It has to be recognised, however, that some have failed—simply because they have satisfied neither the needs of accident prevention nor the legal requirements.

The Legal Requirements

Section 14 (1) of the Factories Act of 1937, which is the law on the subject, relates to the fencing of dangerous parts of machinery, and contains a proviso of great importance to power-press users which says: "Provided that, in so far as the safety of a dangerous part of any machinery cannot, by reason of the nature of the operation, be secured by means of a fixed guard, the requirements of this subsection shall be deemed to have been complied with if a device is provided which automatically prevents the operator from coming into contact with that part."

Fixed Guards and Automatic Guards

In general, it may be said that the Factory Inspectorate branch of the Home Office holds that the fixed guard should be much more widely used.

This attitude is not based on the assumption that, provided skill and ingenuity are employed, any press operation, no matter how large or complicated, can be carried out under the protection of a fixed guard. Such a contention, if true, would imply that automatic guards are used to-day on

FIG. 1.—FIXED GUARD

Guard permits passage of the work, but excludes the hands. (*Ford Motor Co., Ltd.*)

many presses which could—and therefore should, if the law is to be complied with—be fitted with fixed guards.

With regard to heavy presses, the Chief Inspector of Factories, in accordance with well-established practice, set up a small committee on which sat representatives of press users alongside the representatives of the Factory Department of the Home Office. There was an attitude of co-operation and frank facing up to the problems involved, and examination of the steps that had been taken to overcome the difficulties. Whilst it was always kept in mind that the Factories Act clearly states that the fixed guard is the only type acceptable if it is practicable, it was also recognised that on heavy machines the nature of the operations made other devices necessary. The idea of formulating a special code of Regulations to control the guarding of heavy presses was not favoured, it being held that such a code was not advisable, since the dangers to be met, and the best methods of overcoming them, were not obvious enough to justify the enforcement of rules which might still prove ineffective.

The whole subject was in the fluid and formative stage, and more harm than good might be done by such a procedure; for what was wanted was experiment and research, so that the best methods of working and the best design of guards should be achieved. This proved to be an extremely sound view, and although there is still a long way to go, the investigations and the practical co-operation of various pioneering firms have made it quite clear that the policy of using fixed as opposed to automatic guards could be extended without paralysing production or at least so seriously reducing output that major economic problems would result. The importance of the fixed type of guard as a safety device in industry cannot therefore be over-estimated.

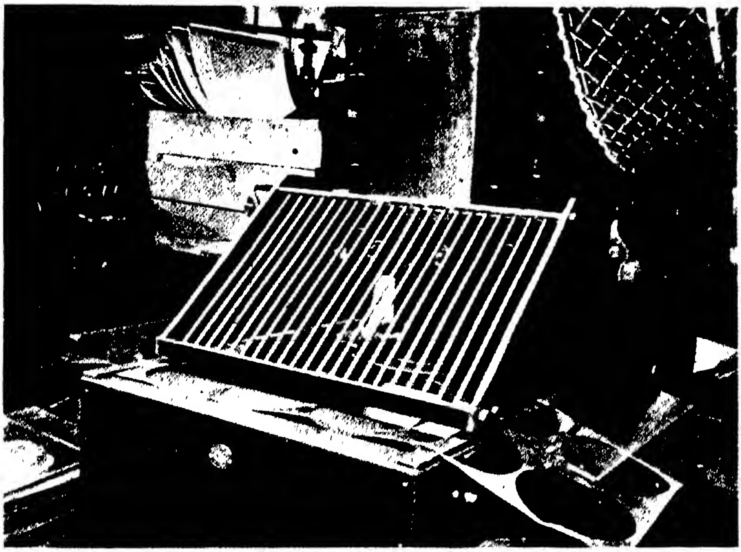


FIG. 2.—FIXED GUARD USED DURING COMBINED BLANKING AND CUPPING OPERATIONS
The formed article is pulled forward with the strip and falls through an opening in the press table into a basket below. The opening is visible below the guard on the right.
(*Taylor, Law & Co., Ltd.*)

Fixed Guards and Feeds

It may be said that in the past fixed guards have been largely confined to operations on the strip. When a combined operation, such as cut and cup, is performed from strip, a specially designed chute is often necessary for the delivery of the work without infringing the legal requirements. This method of fencing is now being considerably developed for work on components which need to be placed on the die. The simplest method from the tooling angle is to provide for feeding through a fixed guard by means of tongs or special grippers. An example of feeding, in which the work has to be placed in position on the die by hand, is illustrated in Figs. 3–6.

The operation involved is the riveting of brackets to fenders, and the assembly for riveting consists of three rivets passed through fender with the round heads outside. Over these is fitted a reinforcing plate and three washers, and finally a bracket of channel section. Prior to inserting in the press, the rivets are kept in position by the operator's forearm, the bracket resting in the curve of his arm and shoulder as shown in Fig. 3.

The three-piece guard is an extended false table made to the same radius as the fender. This section, being wider than the top piece, allows the operator to

FIG. 3.—RIVETING BRACKET TO FENDER

Showing the method of holding the fender to keep the rivets in place prior to inserting in the press. (*Ford Motor Co., Ltd.*)

enter assembly into guard aperture on either right- or left-hand side and to slide the rivets off his arm on to the table. The assembly is then passed through the press until the rivets are felt to locate in dimples in the die. The front plate of the guard is formed to reduce the front aperture.

In Fig. 6 the guard has been removed to show that to carry out the same operation unguarded would take the operator's forearm completely under the ram of the press.

Other methods of feeding the work are chute feeds, slide feeds, dial feeds, and sliding dies. Thus, where a cupped article has to be given a second draw, a horizontal or inclined chute, fed through a fixed guard, is appropriate. If the work is

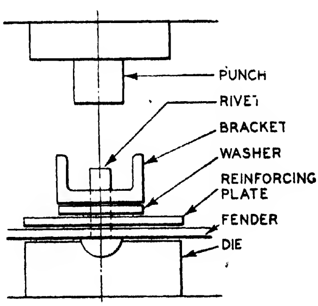


FIG. 4.—RIVETING BRACKET TO FENDER

Details of the assembly shown in position before riveting.

FIG. 5 (*right*).—RIVETING BRACKET TO FENDER

This illustration shows the fender in position for riveting. The operator supports the fender with his shoulder and locates it in the proper position by means of a special tool.
(*Ford Motor Co., Ltd.*)

FIG. 6 (*left*).—RIVETING BRACKET TO FENDER

In this illustration the guard has been removed, to show that to carry out the same operation unguarded would take the operator's forearm completely under the ram of the press.
(*Ford Motor Co., Ltd.*)

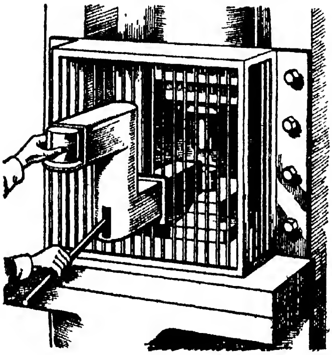


FIG. 7.—CHUTE FEEDING

Showing a method of chute feeding which effectively shields the operator from the press while allowing an article to be fed to the die. It overcomes the difficulty which arises when, in order properly to perform the operation of feeding partially formed articles to the die, the fixed guard would require an opening large enough to permit the hand to enter the danger-zone.

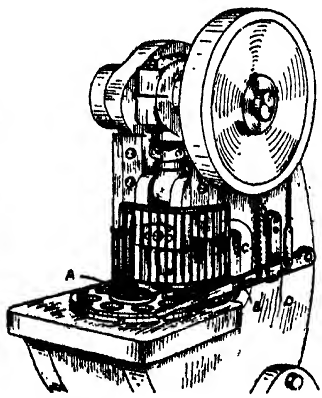
stripped off the punch, a compressed-air nozzle can be used for stripping it off the die, and if applied in conjunction with an inclined table so that the finished work falls into a receiving bin by gravity, a speedy production set-up with a maximum of safety is ensured.

Slide Feeds.—For handling flat blanks for forming, slide feeds are very useful, or for formed articles for piercing, when nest location is in use. The fixed nest in the die surface is replaced by a sliding plate cut out to the component shape and mounted in a slide with suitable locating stops. The slide plate should be made of soft material, so as to minimise the risk of damage to punches, should the press be prematurely tripped.

Punching Operations.—In the case of punching operations, a constant progress of work with conditions amounting to continuous-flow production can be attained with the use of a simple power-operated push feed in conjunction with a slide. The drive for this can be obtained by suitable fittings on the dies.

FIG. 8.—GUARD FOR DIAL-FEED OPERATION

This guard not only prevents access to the danger-zone but obviates the risk of trapping between the lower edge of the guard and the recess in the turntable. The guard is mounted on a loose ring *A* fitted over the turntable axis, so that if a finger becomes trapped between one of the turntable recesses and the left side of the guard, its right side swings against clutch handle *B*, which is kept depressed by the pressure of tension spring *C* against latch *D*, forcing the clutch lever clear of the catch and allowing it to rise, thus disengaging the clutch and bringing the machine to a halt.



Dial Feeds.—Dial feeds are eminently suitable for large-scale production jobs. Operations on cupped articles, such as heading and forming, are suitable for treatment in this way. Even when presses are not specially designed for dial feeds, hand-operated dials are often successfully applied, and give excellent production figures with greatly increased safety. In fact, danger can be completely eliminated. The advisability of obtaining dial-feed facilities is a point that should be kept in mind when installing a new press.

Sliding Dies.—The use of sliding dies in conjunction with fixed guards has also been greatly developed by certain manufacturers who, whilst setting a high standard on their production figures, are fully alive to the value of ensuring safety to the operative, or at least eliminating as many avoidable contingencies as possible. There is, of course, the additional cost to be faced in the initial installation, such as is involved in providing a sliding subtable, but there is little doubt that whether viewed from the production angle or the safety angle, the investment is a good one.

With this method the work in hand is loaded and removed from the die at a point situated conveniently in front of the operator, This obviates the necessity for continual leaning and stretching—an undesirable waste of effort that becomes extremely tiring after a comparatively short space of time.

It is important enough, even under normal working conditions, that a press operator should at all times be fresh and alert. When an extra effort is demanded, such as the strain imposed by overtime, the value of any device whereby human energy can be conserved is to be greatly valued, for in addition to the considera-

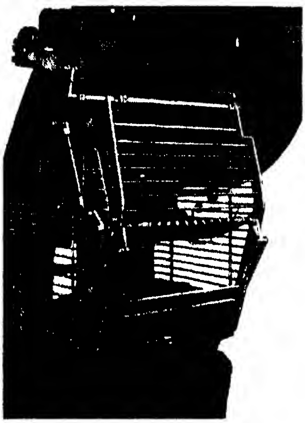


FIG. 9.—HAND-OPERATED INTERLOCK GUARD FITTED TO AN OVERHUNG PRESS (*Press Guards, Ltd.*)

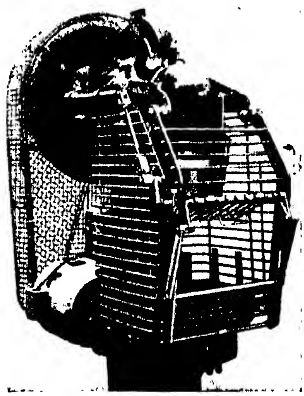


FIG. 10.—HAND-OPERATED INTERLOCK GUARD FITTED TO A STILES PRESS (*Press Guards, Ltd.*)

tion of safety and production previously mentioned, it helps to maintain the general well-being of the worker.

There is a good deal of wisdom in the old saw which says that "men as well as machines can break down."

Interlock Guards

The occurrence of a not inconsiderable number of accidents on short-stroke presses equipped with automatic guards has caused some doubt as to their efficacy under certain conditions. In consequence of this, interlock fixed guards, which makers of power-press guards are equipped to supply, are used. The principle underlying these devices is that all access to the danger area must be cut off before it is possible to set the press in motion, and that the fencing should be maintained until the press has come to rest. When these guards are used, careful routine examination of clutches and routine maintenance of both clutches and drives are necessary to obviate the risk of key failures or flywheel seizures leading to uncovenanted repeats. Press-guard manufacturers can give

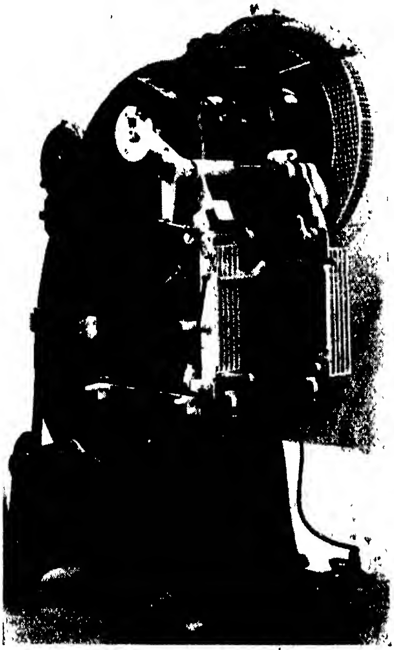


FIG. 11.—PNEUMATIC FOOT-OPERATED INTERLOCK GUARD

(*J. Broughton & Son (Engineers), Ltd.*)

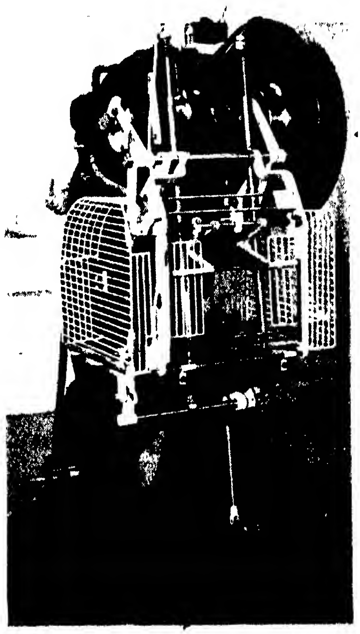


FIG. 12.—MECHANICAL FOOT-OPERATED INTERLOCK GUARD

(*J. Broughton & Son (Engineers), Ltd.*)

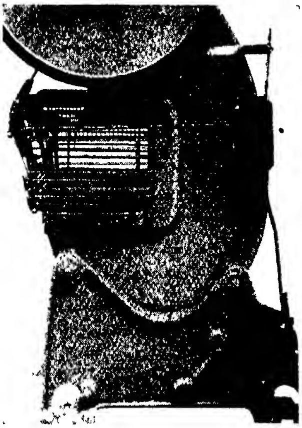


FIG. 13.—"AIRTRIP" UNIT FOR INTERLOCK GUARDS

This unit is used in conjunction with interlock guards, and provides foot closure of the guard and air operation of the clutch.
(Press Guards, Ltd.)

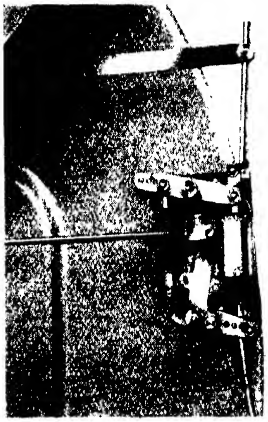


FIG. 14.—"AIRTRIP" UNIT FOR INTERLOCK GUARDS

With the cover removed, the connections to the units are seen with the air valve and clutch-operating cylinder. *(Press Guards, Ltd.)*

sound advice based on varied experience as to the class of presses on which automatic guards should not be used.

Foot-operated Interlock Guards

Foot-operated interlock guards are operated by either mechanical or pneumatic pressure (Figs. 11 and 12), and in both types closure of the guard is intended to take place *before* the clutch can move to engagement.

The two movements, although being sequential, are entirely distinct, and if necessary the guard can be closed and maintained in such position without the clutch automatically engaging.

In the case of the Broughton Vertiscreen pneumatically operated guard (Fig. 11), it is arranged that the compressed-air cylinder is confined to closing the guard and not to engage the clutch. It is constructed so that, in the event of temporary failure of the air supply, both press and guard can be used manually and production continued without interruption.

The mechanically operated guard, shown in Fig. 12, also consists of the well-known Broughton Vertiscreen type, together with additional mechanical equipment to link the foot pedal with the moving screen of the guard so that depression of the pedal closes the screen and simultaneously actuates the guard interlocks in order that the clutch may be free to engage.

FIG. 15.—POWER-ASSISTED (PNEUMATIC) INTERLOCK GUARD FOR HEAVY PRESSES

The guard must be closed before the press can be operated, and is locked in the closed position until the press has completed its stroke.

(*J. Broughton & Son (Engineers), Ltd.*)

"Airtrip" Unit for Interlock Guards

This unit (Figs. 13 and 14) is used in conjunction with interlock guards, and provides foot closure of the guard and air operation of the clutch. Depression of the pedal closes the guard, and the clutch is engaged by an air-operated cylinder. This arrangement frees both the operators' hands. The recommended line pressure of this unit is 40–100 lb. per square inch, and can be fitted to existing interlock guards on presses up to 100 tons capacity.

Automatic Guards

Where variable-stroke presses are concerned, particular care is needed in the application of automatic guards. Most of these presses are calibrated in such a way that the reduction of stroke is achieved by the rotation of the eccentric in the direction of crankshaft rotation. Since the automatic guard is driven by the crankshaft, it will be realised that on intermediate strokes the timing of the guard will be adversely affected. By the simple device of reversing the calibration so that the eccentric is rotated contrary to the direction of the crankshaft, improved timing is gained at intermediate strokes.

Where sufficient space is left on the bolster or bed of a press outside the area of the die, it is imperative, where the space thus left is sufficient to accommodate a worker, to screen and guard adequately against access. When a press is

at rest, with the driving mechanism in motion, no work should be done between tools and dies unless supports are placed so as to prevent descent of the ram.

If the tools used in a particular press job call for adjustment of the safety devices, the adjustments made must not interfere with proper working or efficiency. Moreover, the device which is used to secure safety should also ensure that the operative is, by means of a moving member, screened off or removed to a safe distance before the gap between the nearest trapping parts close to less than 5 in. The moving member of the safety device should be at a height of not less than 3 ft. 6 in. above the standing place of the operative when the press ram is at the top of its stroke. During the actual stroke, access to the bolster area below this height should be prevented by screening.

In the case of a device with an upward-moving member, rising vertically or practically vertically, an attachment of a minimum width of 9 in. should be fitted to the top edge, horizontally towards the trapping area. During the first 6-in. rise this should move outwards towards the operator through an arc of not less than 70°.

Moreover, this moving member, before the trapping distance between tools and dies becomes less than 5 in., should rise so that the top edge of the attachment is not less than 5 ft. 6 in. With the safety device in this position, it is practically impossible for the operative to be trapped between tool and die.

There is no doubt that the large majority of the work which these presses are required to do can be carried on with these standing safeguards.

At the same time it must be remembered that the guarding of many heavy presses, and the components with which they have to deal, presents problems at one time regarded as insuperable. The ever-present necessity for adequately protecting the operator, however, led to rapid development in the design of automatic guards for large presses.

The whole problem of securing real safety when the use of fixed guards is prohibited by the nature of the operations, would be largely solved if by some means the descents of the ram other than those willed by the operator were eliminated. One means of securing this state of affairs has been in use for some time—the positive stop in conjunction with a slipping member incorporated in the flywheel. If the adventitious stroke tends to occur, the press ram is prevented from descending and the flywheel energy is dissipated in the slipping member. But its use is not universal.

Push-button Control

In a press actuated by push-button control, descent of the ram will not take place, provided the push buttons are suitably placed, until all the workers engaged on the machine are pressing a button and standing in a safe position to do so. The safety conferred is illusory, for it does not take into account the fact that it not infrequently happens that an extra worker is brought into the team to cope with a special job. Nor does it provide safety in the event of a repeat stroke, and the object of the push-button device has more than once

been neutralised in practice by "scotching" by the operatives. There have been many accidents following this practice.

On the principle of the old axiom that prevention is better than cure, tools and dies should be designed with safety factors kept clearly in mind. Care should be taken that locating pins or slides are in such positions as not to be within easy reach of any person working at the press. But where this cannot be avoided and a dangerous trap occurs between the locating pin or slide and its corresponding register, then, in advance of the trap between the working surfaces of the tool and the die, secure local fencing should be provided. By a little careful thought in the beginning it is often possible to obviate the necessity for such local fencing by designing tool and die so that the locating pin or slide at no time leaves its corresponding register.

While local fencing may be a counsel of perfection, in actual practice its fitting might adversely affect the smooth-flow working of the press, owing to interference with the loading and unloading. In such cases great care must be taken to see that the trap occurring with respect to the locating pin or slide approximates closely to the trap occurring between the working surfaces of the tool and die. The normal guarding of the press is then an adequate safeguard in itself. Accessible surfaces, other than the faces of the tool, die, and pressure plates, should not meet within 5 in.

"Millo" Ejector Hand-press Guard

The "Millo" ejector hand-press guard shown in Fig. 16 has been designed to provide safety for the operator and also as an ejecting mechanism for removing the finished work from the die. The striking member which removes the fingers of the operator from the die during the early part of the downstroke is fitted with a rubber sweep, and may be used to remove the finished component clear of the tools on its backward stroke, thus increasing production.

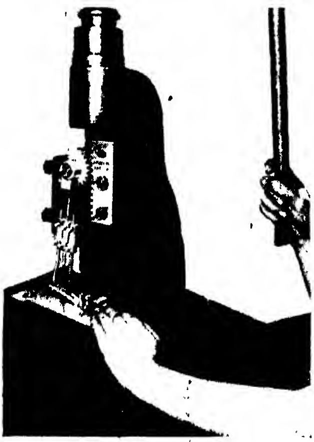


FIG. 16.—"MILLO" EJECTOR HAND-PRESS GUARD

Showing fingers being swept clear of the dies during the early part of the downstroke. (*Press Guards, Ltd.*)

"Warnlite" Accident Prevention System

This is a system developed by J. Broughton & Son (Engineers), Ltd., whereby instantaneous indication is given visibly and audibly, and the machine immobilised when the guard is not working correctly. It has been primarily designed for power presses, but is adaptable to most machines fitted with interlock guards. Fig. 17 shows the diagrammatic layout of the system.

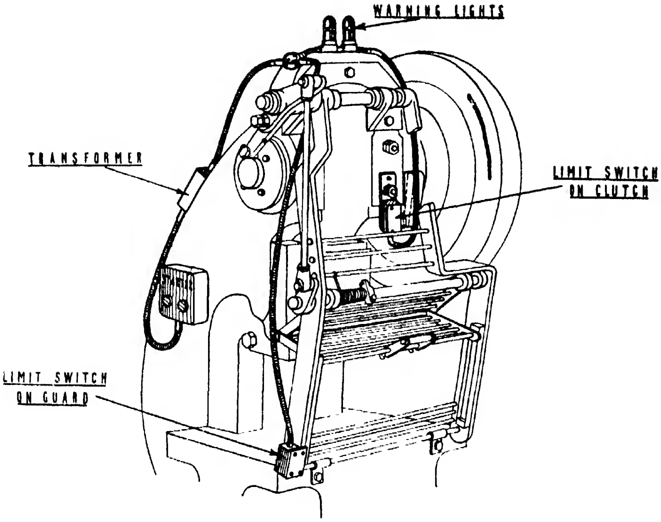


FIG. 17.—DIAGRAMMATIC LAYOUT OF THE "WARNLITE" ACCIDENT PREVENTION SYSTEM
(*J. Broughton & Son (Engineers), Ltd*)

Warning Light.—The warning light operates by a series of limit switches, fitted to the closing screen of the guard and clutch of the machine, which allow current to pass to the warning lights only when the guard is not working correctly. As an additional precaution, the circuit, wired through the "no volt" release in the starter "cuts out" the motor simultaneously.

Group Indicator System.—If desired, a group indicator system can also be supplied for fitting in a convenient place or office so that the Safety Officer or Foreman can, by visible and audible warning, be informed when any guard connected to the group system requires attention.

Audible Warning.—Audible warning is provided through an electric bell which rings at minute intervals, controlled by a 230-volt synchronous motor. The whole system renders the machine out of action until the fault is rectified.

To reset the system, a relay is incorporated, to be operated manually by the controlling authority. The visible and audible warning circuit is 12-volt, a transformer being included, together with means to overcome "voltage drop" on indicators situated at a greater distance than 50–100 ft. from the machines.

GUARDS FOR GUILLOTINES AND MACHINE TOOLS

The fitting of guards to the various types of machine tools present, in many cases, difficulties to the efficient operation of the machine, in that the operator may need to have constant access to the job. A typical case is the operation of

FIG. 18.—FRONT VIEW OF GUARD FOR STRADDLE MILLING FOUR GEAR BLANKS

The bridge clamps can be swung clear of the components for loading and unloading. The openings in the cutter guard are too small to allow the cutters to be reached by fingers, even when the clamps are down. (*Ford Motor Co., Ltd.*)

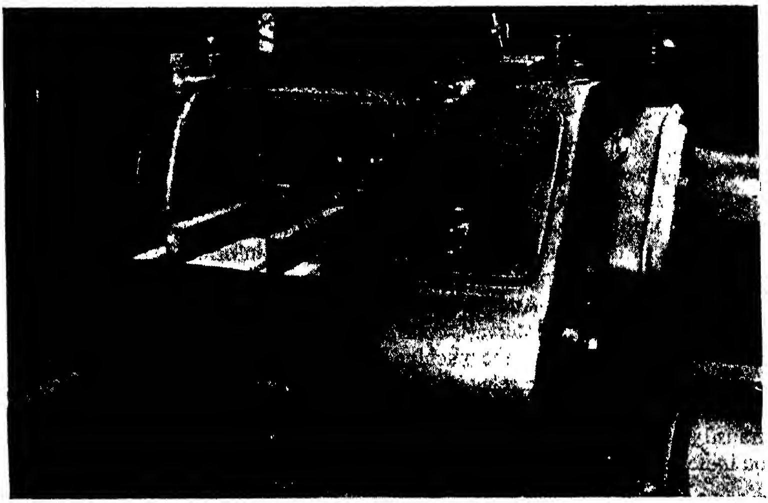


FIG. 19.—REAR VIEW OF GUARD FOR STRADDLE MILLING FOUR GEAR BLANKS

A tray of ⅛-in. mild-steel plate is fitted to the table at a height equal to that of the upper face of the components. Allowance is made for lowering of the cutters as they wear by clearance between the guard and the tray. Wood strips are screwed to the tray to fill up the gaps provided for the bridge clamps. (*Ford Motor Co., Ltd.*)

FIG. 20.—GUILLOTINE FITTED WITH FRONT GUARD

This guard covers the pressure pads, but is stepped in at intervals to allow narrow strip to be handled. (*Ford Motor Co., Ltd.*)

sliding, surfacing, and screw-cutting lathes. These machines are manually operated, and for instance, in boring or cutting internal screw threads, the operator must be able to get close to the work to inspect its progress.

In the majority of cases, however, it is possible to design special guards, particularly for machines employed for repetition work. Examples of typical guards are illustrated.

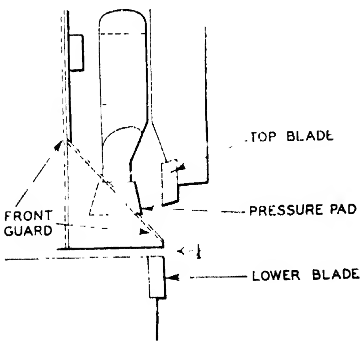


FIG. 21.—DIAGRAM OF GUILLOTINE FITTED WITH FRONT GUARD

Guillotine fitted with Front Guard

With guillotines, the pressure pads operating ahead of the guillotine blade form a great hazard, as their stroke is usually such as to allow fingers to pass under them. A guard running across the face of these pads would mean that the operator could not handle narrow stock, due to the guard being some distance out from the blades.

The guard shown in Fig. 20 has been designed to cover the pressure pads and to allow stock feeding and control to within approximately 1 in. This design also adds to the rigidity of the guard, and with the use of slotted material gives good vision.

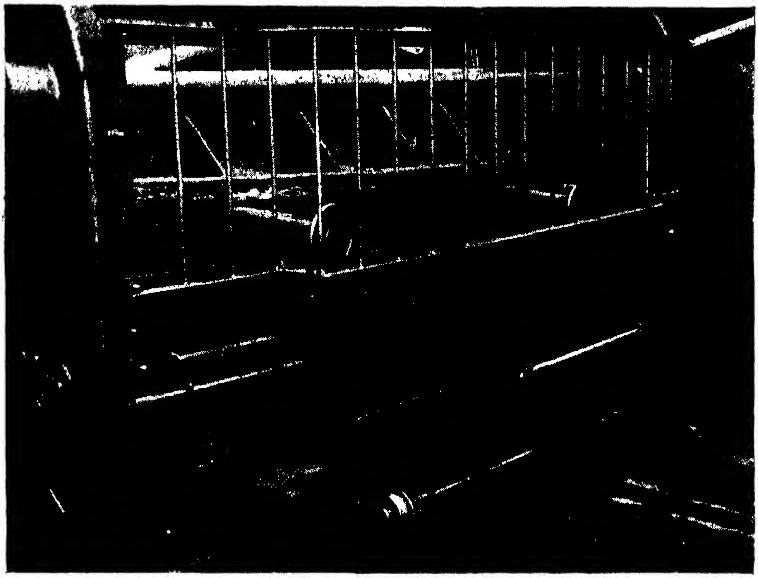


FIG. 22.—GUILLOTINE FITTED WITH REAR GUARD

It will be seen that the guard prevents any access to the blades.

This illustration shows the trolley under the guard for collecting the cut strip, the trolley rails being built up over the rear tie-bar of the machine. (*Ford Motor Co., Ltd.*)

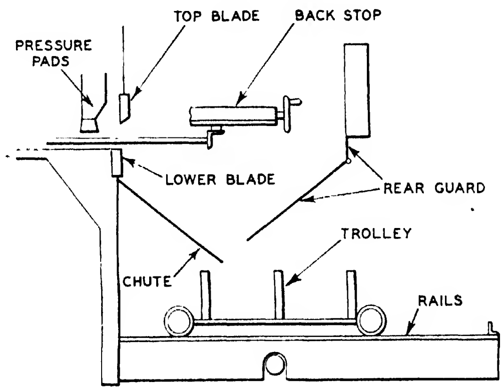


FIG. 23.—DIAGRAM OF GUILLOTINE FITTED WITH REAR GUARD

FIG. 24.—GUILLOTINE FITTED WITH REAR GUARD
Showing the trolley withdrawn from under the guard. (*Ford Motor Co., Ltd.*)

Guillotine fitted with Rear Guard

In the machine illustrated in Figs. 22–24, the cut lengths are ejected from the rear on to a specially constructed truck. It will be seen that it is desirable to have a guard fitted to prevent any access to the blades.

The arrangement consists of a chute which stretches across the full width of the machine, and is secured close up to and below the bottom blade, and inclines downwards approximately 30°. Cut metal falling to the rear slides away down this chute on to a trolley which, running on rails built up over the rear tie-bar, will pass under the chute. Adjustable plates across the trolley guide the cut strip into a tidy stack, and movement of the trolley in or out will permit full loading.

Wire-rope slings of an overhead crane can then easily be passed around the lift, either at the overhanging ends or through the slots provided in the trolley bottom. This arrangement eliminates a large amount of handling and stacking.

The rear guard is in two parts, the upper section is bolted to the side frames of the machine, and the lower section, which is attached to the upper section, is bolted in a position slightly out and above the bottom edge of the chute.

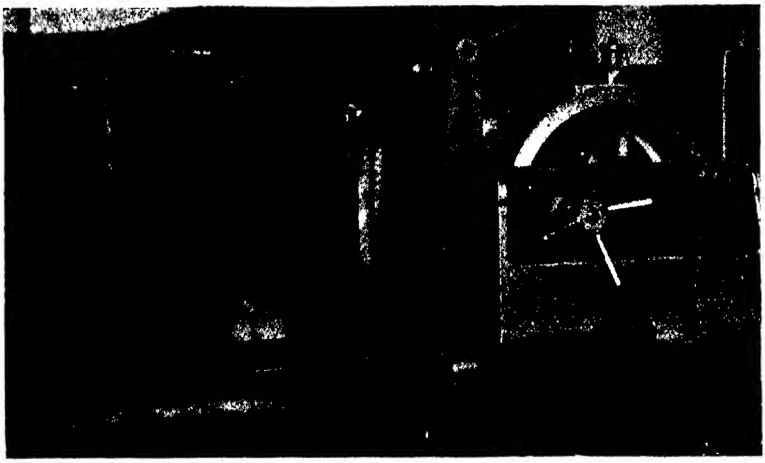


FIG. 25.—GUARD FOR LARGE FACE MILLING CUTTER

The cutter diameter is approximately 18 in. The work is shown passing towards the cutter. The periphery of the cutter is guarded by a fixed "ring" guard, and the perforated plate guard shown travels with the table, thus uncovering the face of the cutter only as the work covers it.
(*Ford Motor Co., Ltd.*)

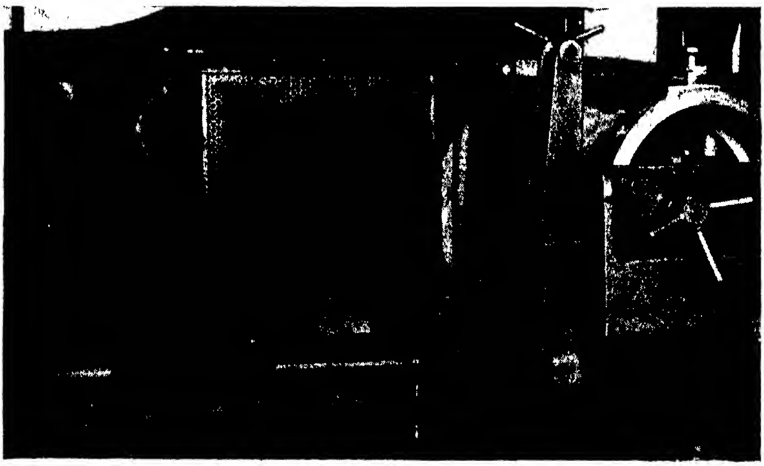


FIG. 26.—GUARD FOR LARGE FACE MILLING CUTTER

As the work recedes from the cutter the guard follows, covering the face of the cutter as the work leaves it exposed. While loading and unloading, the cutter is totally enclosed.
(*Ford Motor Co., Ltd.*)

The construction of the guard permits adjustment of the rear stops and feeding from the rear when the cut required exceeds the limit of the rear stop. In the latter case, the cross bar of the rear stop is taken away.

Plastic Guards for Machine Tools

Clear acrylic resin sheet is now finding increasing application as a constructional material for machine guards, protective screens, and other safety devices. Guards made of this material allow a clear view of the work and moving parts and give complete freedom from shadow. They may be fitted quite close to the work, and in addition to giving protection against injury prevent the accumulation of dust and grit.

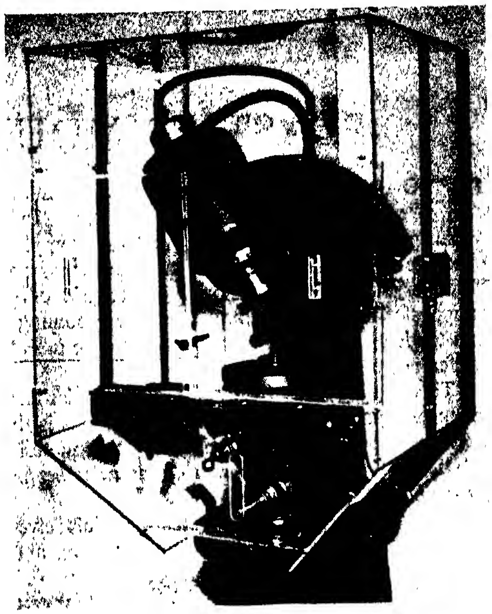


FIG. 27.—TRANSPARENT PLASTIC GUARD

This shows a "Perspex" case completely shrouding a boring machine. (*Imperial Chemical Industries, Ltd.*)

A "Perspex" case completely shrouding a boring machine is illustrated in Fig. 27.

Special thanks are due to the Ford Motor Co., Ltd., Taylor, Law & Co., Ltd., J. Broughton & Son (Engineers), Ltd., Press Guards, Ltd., and Imperial Chemical Industries, Ltd., for having so generously provided details concerning the latest types of guards and safety devices which are dealt with in this article.

E. M.

PLASTICS MOULDING

To many people the word "plastics" implies the use of substitute or "ersatz" materials. During and immediately after the period 1937–45 plastics were used for a great many applications, owing largely to the shortage of normal materials. Plastic curtains, plastic lampshades, and plastic "crockery" are three outstanding examples of this type. To-day, when the supplies of textiles, glass, and china are becoming more readily available, there is a tendency for the public to revert to the use of the traditional materials in preference to substitutes.

This veering away from the use of plastics has not occurred in the case of engineering applications. The reason for this is that engineers have seldom or never used plastics as substitutes for other materials. In the engineering world plastics are used *only where they provide the most suitable material for the particular purpose in view.*

For instance, plastics laminated materials have been for many years used in the insulation of electric generators, motors, and transformers because they have proved to be best for the purpose.

Again, laminated plastics gears are used for certain engineering applications, not because of the shortage of other materials, but because plastics gears have been found more suitable. The same applies in the case of plastics bearings and for many other purely engineering applications.

Quite apart from the uses of laminated and moulded plastics in certain types of engineering equipment, the whole subject of plastics manufacture is of particular interest to mechanical engineers, because so many problems of mechanical engineering are involved in their manufacture. For instance, the construction operation and maintenance of moulding and laminating presses, and the manufacture of the steel moulds and dies which are used in the processes, fall naturally within the province of mechanical engineering.

It is these factors that have led to the inclusion of the present article in this work, which is designed to be of direct use to mechanical engineers.

Definition of Plastics

Plastics are organic substances which can be moulded to shape, usually under heat and pressure, during some stage in their manufacture. This definition includes rubber, however, which has an established technique of fabrication peculiar to itself, and which is therefore considered as a separate subject.

In general, plastics may be divided into two classes, thermoplastic and thermosetting. The former are softened by heat and formed to the required

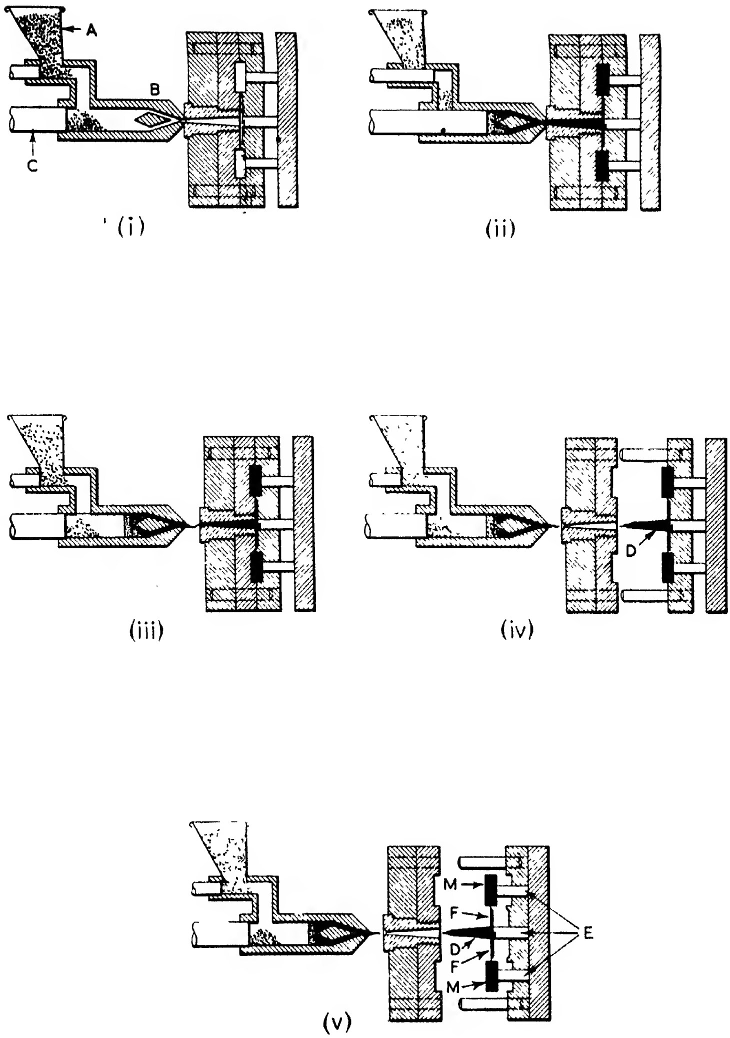


FIG. 1.—INJECTION-MOULDING PROCESS
(*T. H. & J. Daniels, Ltd.*)

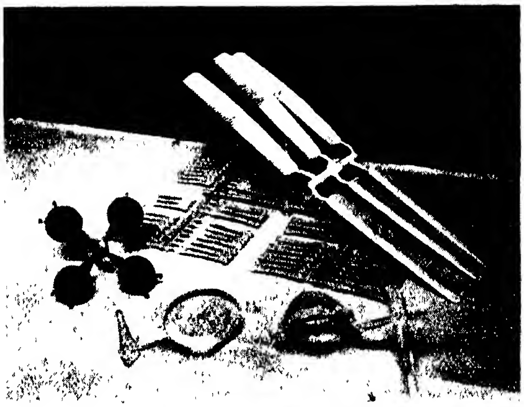


FIG. 2.—SOME EXAMPLES OF INJECTION-MOULDED ARTICLES
(*T. H. & J. Daniels, Ltd.*)

shape, afterwards being "set" by cooling, while the latter, after being moulded in a hot, plastic state, become chemically changed on further heating and set hard. It is apparent that thermoplastic materials can theoretically be reformed any number of times, while thermosetting ones cannot, as the baking (or "curing") action is irreversible. They are all made up of complex molecules of a type called polymers, which are produced from a relatively simple molecule known as the monomer.

We give below examples of these two classes of plastics.

THERMOPLASTICS.—Cellulose acetate, cellulose nitrate (celluloid), methyl methacrylate (Perspex and Diakon), polystyrene, polythene (Alkathene), polyvinyl chloride (P.V.C.), polyamides (Nylon), ethyl, and benzyl cellulose.

THERMOSETTING PLASTICS.—Phenol-formaldehyde (Bakelite), urea-formaldehyde (Beetle), melamine formaldehyde (Melmac).

INJECTION MOULDING OF THERMOPLASTICS

The most widely used method in the fabrication of thermoplastics is injection moulding. The machines used may have capacities ranging from fractions of an ounce to over 30 ozs., and are operated either by hand toggle, pneumatic or hydraulic mechanisms.

The material in the form of a coarse granular powder is fed into the machine, pushed by means of a plunger through a heated cylinder, where it becomes a plastic mass, and thence into a nozzle from which it "injects" into a closed die of the required shape. On withdrawing the plunger and opening the die, the moulded article can be removed, attached to its "sprue."

This process is illustrated diagrammatically in Fig. 1. In—

(i) a measured amount of material has fallen from the hopper (*A*) into the injection cylinder (*B*), while the plunger (*C*) is about to push it forward through the cylinder, the mould being closed.

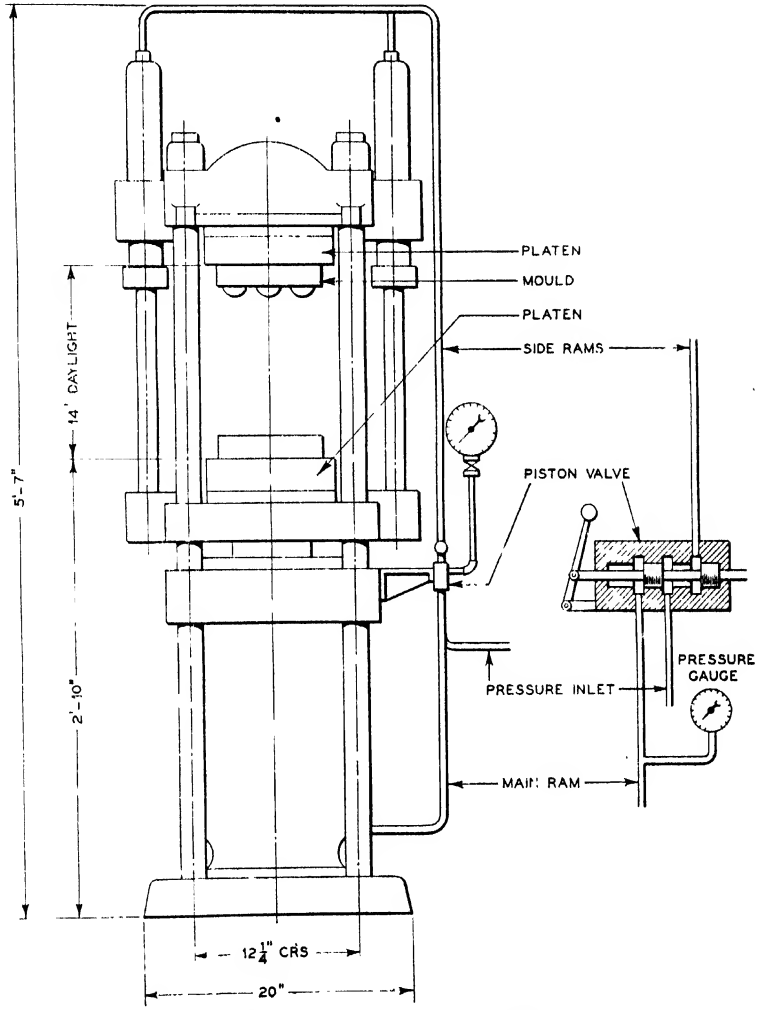


FIG. 3.—UPSTROKE MOULDING PRESS
(*T. H. & J. Daniels, Ltd.*)

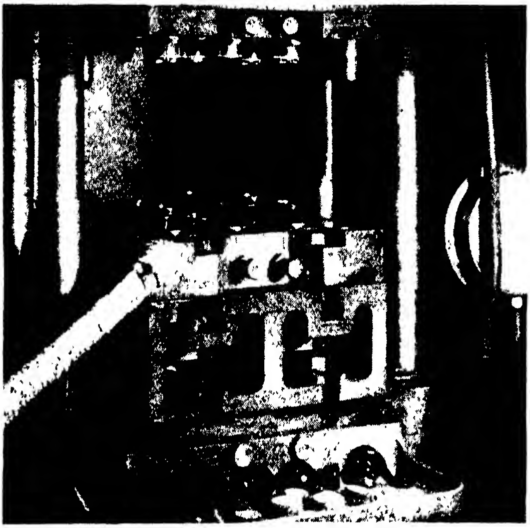


FIG. 4.—COMPRESSION MOULDING

Three different mouldings produced in pairs in a six-cavity mould. (*Alfred Herbert, Ltd.*)

(ii) The plunger has come forward, and the plasticised mass is being forced into the die.

(iii) The plunger is withdrawn, and a further "charge" falls into the cylinder.

(iv) The die opens, and the moulding is shown in position, complete with sprue (*D*).

(v) On retracting the mould plate still farther, the moulding is ejected on the pins (*E*).

The sprue and runners (*D* and *F*) can easily be broken off and reground, and the mouldings (*M*) will only require a small amount of finishing at the point of break.

The injection pressure varies between 5 and 10 tons per square inch, depending on the material, e.g. Diakon and Nylon need more pressure than cellulose acetate. Also the mould may be water-cooled, as in the case of cellulose acetate, or warmed, as with Nylon. The correct conditions must be worked out for each material, and often for the individual moulding.

The locking load, i.e. the force needed to keep the dies closed, must theorctically be just greater than *injection pressure* $\times$ *projected area of moulding*. In actual fact, as the plastic material is not a perfect fluid and, moreover, begins to "set" as soon as it touches the mould, it can be considerably less. It follows that mouldings of much greater area than theoretically possible can be made on a machine of given locking load—up to four times as great, for example, with simple mouldings of cellulose acetate, although considerably less with materials such as Nylon, which are injected in a more liquid state.

AMERICAN LOW-PRESSURE SYSTEM.—This utilises a screw extruder for plasticising the material, which is moulded at a much lower pressure. It is claimed that a 48-oz. moulding can be produced with a mould-locking load of only 150 tons; with a traditional type of machine, about 1,500 tons would be required.

Many familiar household articles are injection moulded in one or other of the thermoplastic materials—toys, ornaments, kitchen measuring-spoons,

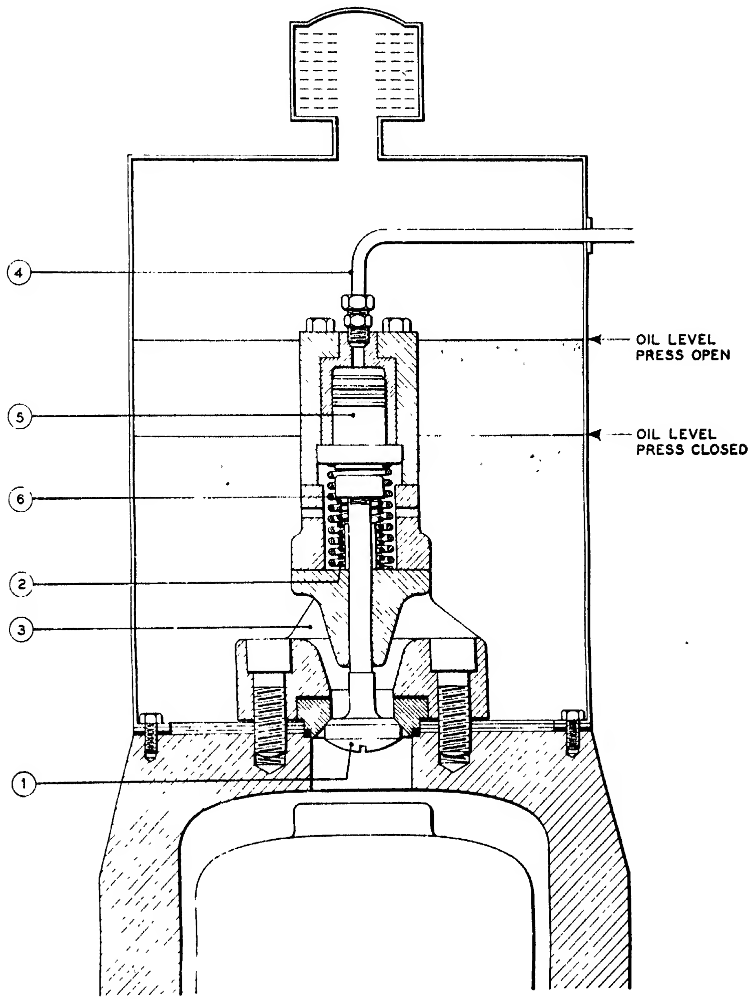


FIG. 5.—PREFILLER VALVE USED ON DOWNSTROKE PRESSES
(T. H. & J. Daniels, Ltd.)

portable radio cases, and many others (Fig. 2). This method of fabrication is becoming more widely used for technical applications, however, particularly in view of the excellent properties of some of the newer materials. Polystyrene and polyethylene, for example, have excellent electrical resistance at high frequencies, making them very suitable for components of radar sets. Nylon, by its toughness and inertness to a wide range of chemicals, has been used for hypodermic syringes, parts of textile machinery, and gaskets in chemical plant. Uses in the automobile industry are rear lamps of polymethyl-methacrylate (Diakon), horn buttons, distributor caps and accumulator caps of polystyrene, and dashboard knobs in cellulose acetate.

COMPRESSION MOULDING OF THERMOSETTING MATERIALS

The commonest method of fabrication for thermosetting materials is that of compression moulding.

This method is carried out in an hydraulic press (Fig. 3), which consists essentially of a cylinder into which the hydraulic fluid (water, oil, or an oil-water emulsion) is pumped, and which forces a ram, attached to a moving table, against a fixed table. The two halves of a mould (Fig. 4) are attached to these tables, and therefore pressure can be exerted on anything with which the mould is filled. Presses can be either of the upstroking or down-stroking type, and provision is made for heating the mould, either by incorporating electric elements or steamways, or by means of heated platens attached to the press tables. Gas heating can be used, but is not so popular.

A weighed quantity of moulding powder is placed in the bottom half of the mould, which is at a temperature of from 310° F. to 360° F., depending on the type of material. The press is then closed and, as the pressure builds

FIG. 6A.—SIDE-RAM PRESS

Split moulds for producing trafficator arms with die-cast inserts. (*Alfred Herbert, Ltd.*)

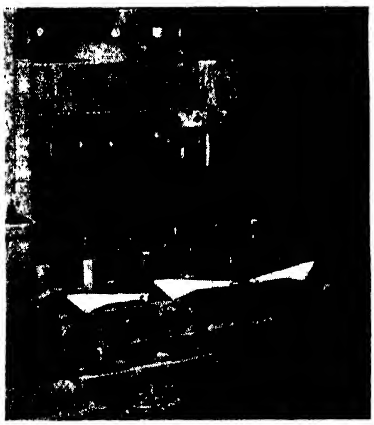


FIG. 6B.—SIDE-RAM PRESS, MOULD OPEN

Opening and closing mechanism is operated by a side ram. (*Alfred Herbert, Ltd.*)

up, this combination of temperature and pressure causes the powder to become plastic and flow into all parts of the mould. The moulding remains under pressure for a specified length of time known as the cure period, after which the press is opened, and it can be ejected, either mechanically or by means of a small hydraulic cylinder.

Moulding pressures vary from 1 ton per square inch for simple phenolic mouldings to 2–3 tons per square inch for urea and melamine.

The decision whether an upstroking or downstroking press should be used depends on several factors. Upstroke presses are simpler in construction, and the return stroke can be made under gravity (although in practice return cylinders are frequently fitted), but they are wasteful of hydraulic power, as the whole of the approach stroke uses pressure fluid. Downstroke presses, on the other hand, can close under gravity, thus saving hydraulic power, the liquid entering the cylinder from an overhead tank through a prefiller valve.

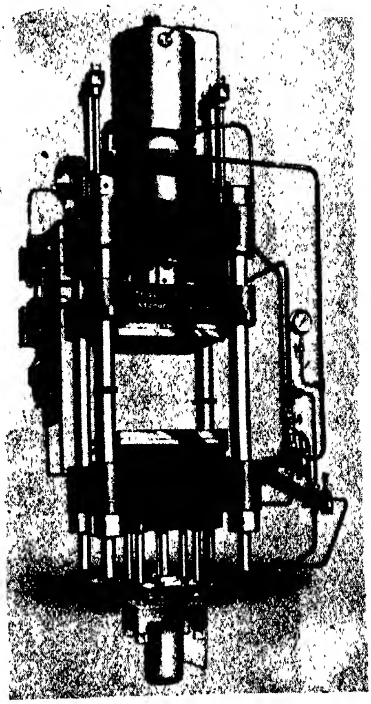


FIG. 7.—TRANSFER PRESS
(T. H. & J. Daniels, Ltd.)

VALVE ACTION. -The action of the valve (Fig. 5) is as follows:

When the press is in the open position and the pressure in the return cylinders is released, the main ram and moving table fall by gravity. Suction is thus created in the main cylinder. This opens the prefiller valve (1) against its spring (2), and the fluid is drawn from the prefiller tank through the ports (3). When the moulds meet and pressure is applied, the valve (1) closes and fluid pressure is built up. To open the press, pressure is released from the main cylinder and applied to the return cylinders. Pressure is also simultaneously applied through the pipe (4) to the plunger (5) which travels against its spring (6) and opens the prefiller valve by pressing on the top end of its spindle. As the press opens, fluid can then flow back from the main cylinder into the prefiller tank through the ports (3). As soon as pressure is released from the return cylinders, the spring (6) returns its plunger (5) and the cycle can recommence.

The speed of closing should be about 120 in. per minute, and to attain this speed with an upstroke press of similar size an uneconomically large

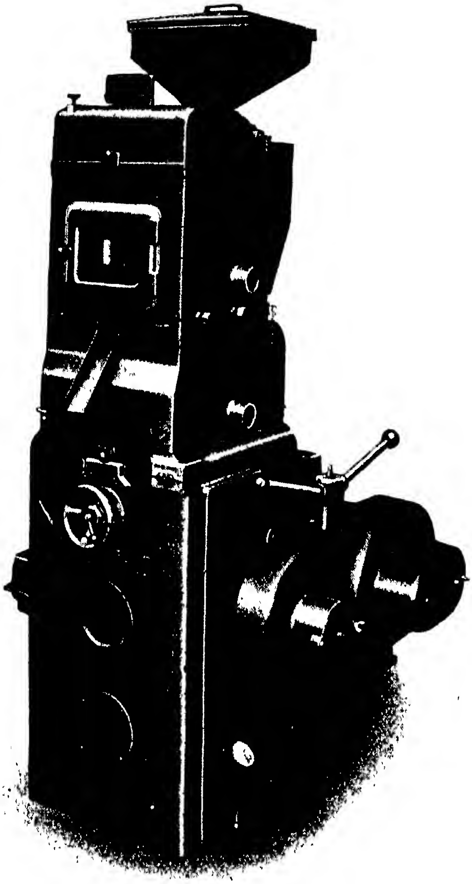


FIG. 8.—PREFORMING MACHINE FOR TABLETS UP TO 1½ IN. DIAMETER × ¾ IN. DEEP
(*T. H. & J. Daniels, Ltd.*)

pump would be required. In the U.S.A., where power is relatively cheap, this is not such a disadvantage, and upstroke presses are popular. A further advantage of downstroke presses is that the working table is at a fixed height. Also under this table there is space for an hydraulic ejector cylinder which may be very necessary when removing complicated or "deep draw" mouldings from the mould.

UPSTROKE OR DOWNSTROKE PRESSES. — In general it may be said that upstroke presses are used for simple jobs or those made in loose moulds which can be removed from the moulding press and opened in special fixtures. Downstroke presses are preferable for rapid production in fixed moulds.

SIDE-RAM PRESSES.—For certain articles, i.e. those with undercut portions, it may be necessary to split the mould vertically as well as horizontally. In these cases a side-ram press (Fig. 6) may be used to give the horizontal clamping pressure.

TRANSFER MOULDING OF THERMOSETTING MATERIALS

When moulding articles of intricate shape or thick section, the transfer process offers many advantages over normal compression moulding. This in principle is similar to the injection process for thermoplastic materials, in that the heated plastic mass is forced into a closed die by means of a plunger. A

vertical press is usually employed with an auxiliary transfer cylinder as shown in Fig. 7.

The material (usually in the form of pellets) is fed into a heated pot; the press is then closed and locked under pressure, the plunger drives the semi-plasticised mass through a narrow gate, where it becomes completely plasticised due to the friction, and the cure takes place almost immediately in the mould, which is also heated.

It will be seen that, owing to the small area of cross section of the plunger compared with the transfer ram, a high pressure can be exerted in the mould cavity, and that therefore a large locking cylinder is necessary.

As with injection moulding, theoretically the locking load should be equal to the injection pressure multiplied by the projected area of the moulding, but here again in practice it can be far less. It is standard practice in America for the ratio of locking to transfer ram areas to be about 7–1, but in England ratios as low as 3–1 have been used successfully.

Examples of Thermosetting Mouldings

These are found in all branches of industry quite apart from their many domestic applications.

Compression moulded articles include radio cabinets, electrical fittings of all descriptions, fan and pump housings, and telephones.

Examples of transfer moulding are wireless-valve bases, motor-car distributors, hand microphone part of telephones, miners' head lamps, door knobs and handles, and electrical fittings where delicate inserts are involved.

Pelleting

When moulding either by the compression or transfer process, it is frequently advantageous to form the moulding powder into pellets or "preforms." This obviates the necessity of weighing each charge, since the pellets can be produced to sufficiently fine weight limits. Also, if a bulky powder is being used, it is densified by pelleting, and thus takes up less room in the mould. Pelleting machines may be of the single or multi-punch type. The former are in more general use, and the one shown in Fig. 8 produces up to 3,600 pellets, 1½ in. diameter, per hour in the normal grades of phenol, urea, and melamine formaldehyde powders. For smaller-sized pellets multiple tools can be used with correspondingly increased output.

Multiple-tool rotary machines are employed when very large numbers of preforms are needed, and in the past they were preferable for use with light urea powders, with which the older type of single-punch machine did not deal so readily.

COMPRESSION MOULDING OF THERMOPLASTIC MATERIALS

Thermoplastic materials may be moulded in ordinary compression moulding presses, but provision must be made for alternately heating and cooling the mould. This is invariably done by using steam-heated and water-cooled platens,

or else drilling the mould to allow for this. Production is not so rapid as with injection moulding, and this method is, in general, used for experimental work.

CASTING THERMOSETTING RESINS

Thermosetting resins can be cast without any fillers, and give hard, glass-like products on prolonged baking. The moulds are usually made from lead by dipping a hardened-steel "master" into the molten metal. The uses of cast resins are mainly for decorative articles, such as umbrella handles, bangles, and ornaments, although it is very suitable for articles such as jugs for carrying acid. Press tools for sheet light alloy work are also made from the unfilled resin, and it can be cast into sheet form in glass moulds.

Cast phenolic resin, with a suitable asbestos filler, has been used widely in the chemical industry for constructional work. Dyeing tanks, steel pickling plant, piping for carrying corrosive liquids, etc., are made from this material.

EXTRUSION

There are two principal types of extruding machine, the screw and the plunger type. In general the screw type is used for thermoplastic materials and the principle of operation is as follows:

The Screw-type Machine

Powder is fed into a heated cylinder, and is carried forward by a screw working against a heavy thrust bearing. The heating, which can be by means of electrical elements clamped round the cylinder or by steam or hot oil jacketing, plasticises the material and enables it to be forced through a die of the required shape to produce rods and tubes of any desired section. The extrusions are usually carried away on moving belts, where they become cool and rigid.

The screw extruder is also used for wire or rod covering by feeding the wire

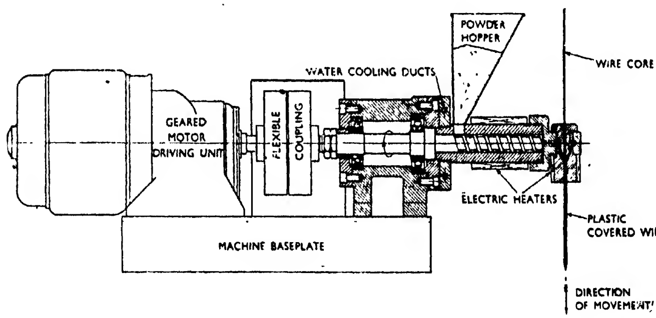


FIG. 9.—DANIELS' SCREW EXTRUDING MACHINE (*Alfred Herbert, Ltd.*)

FIG. 10.—ALKATHENE FILM (*Imperial Chemical Industries, Ltd.*)

through the die at the same rate as the plastic extrusion (Fig. 9).

Plastics Materials Processed by Extrusion

Cellulose acetate, P.V.C., and casein (before formalising) are three of the commoner materials processed by this method, and the resulting sections have uses in many directions. Casein and cellulose acetate are mainly used for domestic and fancy goods, e.g. buttons, fountain-pens, knitting-pins; but P.V.C. tubing, because of its good chemical and electrical properties, is now being used for handling corrosive liquids, as sheaths for electric cables, as beading between motor-car body sections, and for petrol pipes.

Polyethylene can also be extruded in a similar way for similar purposes, and recently has been produced in the form of very thin-walled tubing for the packaging of food-stuffs, for which this material is very suitable, owing to its water resistance and inertness to attack by normal solvents.

The Plunger-type Machine

The plunger type of extruder again consists essentially of a heated cylinder complete with die, through which the material is forced, but in this case by means of a plunger instead of a screw. In this machine the plunger is moved with a reciprocating motion by a crosshead attached to a hydraulic ram. Thermosetting extrusions can be made on this machine, since, owing to the positive nature of the process, none may be left in the cylinder to set and consequently "jam" the machine as could happen in the case of a screw.

The Extrusion Method

Powder is, as before, fed into the heated cylinder, is pushed along to the full stroke of the plunger, and then the latter is rapidly withdrawn, more powder

FIG. 11.—REMOVING THE PERSPEX SHAPE FROM FORMER AFTER COOLING (*Imperial Chemical Industries, Ltd.*)

falls into the cylinder, and is compressed against the previous charge so quickly that a continuous plastic mass is formed which "sets" as it is forced out of the die.

This method of production is suitable for parts which can be cut from a continuous length of the required profile. Such items also as beadings, electrical contact strips, skirting, etc., can be produced by this method. Large rolls for duplicating machines are also made this way.

SHEETING

This covers a very wide range of products made by equally varied processes. Practically all plastics can be produced in sheet form, and the method used depends on such factors as:

(1) Specific properties of the material.

(2) The thickness and accuracy of sheet required.

(3) Whether continuous rolls of sheet are needed or individual sheets of specific size.

The thinnest form of sheet is known as film, and is usually transparent and made from celluloid, cellulose acetate, ethyl cellulose, styrene and Alkathene, as well as regenerated cellulose or cellophane.

Film Making

Film can be cast from solution, precipitated by reagents, and cast, as in the case of cellophane, or extruded. In the first case, the solution in a suitable solvent is fed on to a highly polished metallic band (usually of copper or plated with nickel or chromium). It is fed at an even rate through a narrow slit, and the band carries it away through a heated drying chamber, where the vapour passes off and can be recovered. At a certain stage in the process, when sufficient solvent has been driven off, the dried film is stripped and wound on to rollers.

In the case of the wet process, the cellulose solution (usually as sodium xanthate) is pumped through a narrow slit into an acid solution, where the cellulose is precipitated, and is then passed over rollers and through a series of washing, plasticising, and dyeing tanks before finally being dried and wound on to rollers.

Recently, film-making by the extrusion and subsequent stretching of the

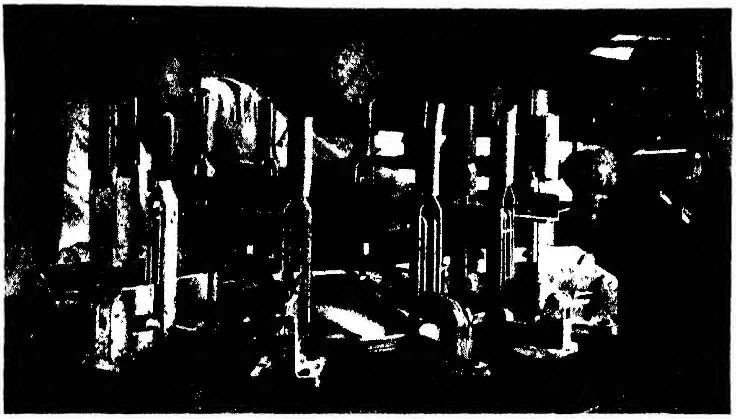


FIG. 12.—FIRST STAGE IN THE BLOWING OF A BABY'S BATH IN PERSPEX
(*Imperial Chemical Industries, Ltd.*)

extruded product has been developed. A normal type of screw extruder is employed as previously illustrated, but the material can either be extruded through a long narrow slit or through a circular die giving a large thin-walled tube. In the former case the film is passed over driven rolls, which extend it while reducing its thickness, thus orientating the molecules and giving it greater strength in one direction. The material produced by the circular extrusion method is expanded by inflating it with compressed air as it comes from the orifice, and then passing it between rolls to flatten it, the edges being trimmed to produce two flat strips of plastics sheet. The latter method has been perfected, particularly in the case of Alkathene, which is now becoming more widely used as a packing material owing to its extreme inertness and moisture impermeability. The cellulose films are widely used in the photographic industry and, more recently, films of high dielectric strength, such as styrene and Alkathene, have come to the fore for use in condensers and other electrical components. Alkathene tubular film is shown in Fig. 10.

Calendering Process

Quantities of thin sheet, particularly of vinyl polymers, are made by the calendering process. The material in the form of heated "hides" is fed on to the first of a series of heated rolls. There are usually three or four rolls employed, arranged vertically and fed from the top, the distance between the last two being very accurately controlled, so that the thickness of the finished sheet is consistent.

By this method also, vinyl compounds are calendered on to a cloth base to give a tougher product, suitable for industrial belting.

Pressed Sheet

Thicker sheets of thermoplastic materials are usually made by pressing between highly polished metallic sheets in hydraulic presses. By employing engraved plates, embossed designs can be produced on the finished plastic.

Casein sheet is made by the "pressing" method. The raw material, after mixing with dyes, plasticisers, etc., is extruded in the form of rods or small "nibs." These are then arranged on sheet-metal moulds in such a manner as to give various designs. The moulds are then placed in heated multi-platen presses. After a certain time has elapsed, depending on the thickness of sheet, they are then cooled by passing water through the press platens. They are hardened by pickling in formalin solution, after which they are straightened by again pressing between metal sheets in similar multi-platen presses, but under lower pressure. The presses are always of the upstroking type.

Casein sheet is used mainly for decorative purposes and for manufacturing such fancy articles as buttons, buckles, etc. However, small electrical parts can be made from it, e.g. "on-off" buttons and other components, where the rather bad water resistance of casein is no disadvantage.

Thermosetting Plastics Sheet

In the case of thermosetting materials, as they are not capable of being plasticised to the same extent as thermoplastics, they are rather too brittle to be used in sheet form in their usual state. Generally, some sort of base, such as cotton, cloth, paper, or wood, is incorporated to give the necessary strength. The resin is used in a suitable solvent to give a sufficiently low viscosity, and the filler is thoroughly impregnated with it by passing it through a trough of the liquid, squeezing out the excess through rolls, and then drying in an oven. The impregnated material, which is by now similar to a stiff cardboard, is then cut to the necessary size, several sheets stacked together and pressed in a multi-platen press similar to those previously described. This method of manufacture applies to paper and cloth-based laminates. Where wood is the base, sheets of thin veneer are impregnated with resin by placing them in tanks from which air can be exhausted, so that the resin enters into the wood cells very intimately. After a certain period of time, the plies are removed, dried, and several are pressed together in the same type of press as mentioned above.

By varying the direction of the grain, the product can be made to have maximum strength in different directions.

Applications of Laminated Plastics

It will be evident that impregnated sheets, having varying bases, can be combined together, e.g. a fabric-based material can be faced with one that is paper-based. In this way decorative effects on the surface can be achieved while the backing may have different properties. For example, a sheet of paper on which is painted a design or picture can be impregnated with a pale-coloured melamine syrup and laminated on to a cloth-based phenolic resin.

Apart from decorative uses, however, laminated plastics are very important in the industrial field. They are extremely tough, are resistant to many of the commoner solvents, as well as being vermin- and bacteria-proof. They are used for silent gears and bearings—graphite can be incorporated in the impregnating process in order to provide self-lubrication. The electrical properties in general are good, and so paper- and cloth-based resins are widely used for parts of switches, contacts, junction boxes, etc.

Wood-based plastics are used for airscrews and various parts of textile machinery where previously wood or leather were solely employed, but were never entirely satisfactory owing to their very high replacement factor. A very important use is for mechanically stressed electrical components, such as parts of circuit breakers and insulating fish plates.

MISCELLANEOUS METHODS OF MANUFACTURE AND FABRICATION

Many plastic articles are made by miscellaneous methods which do not come under any of the above headings, since they do not utilise specific machines.

For example, when making final products from laminated stock, ordinary woodworking lathes, routers, etc., are used, and these are too well known to require description.

As shown in Fig. 12, simple hemispherical or domed shapes can be made from sheet by blowing. Here the heated sheet is clamped in position, and a controlled supply of compressed air is utilised to produce the necessary shape. Complete spheres can be made by cementing two hemispheres together with a suitable solvent, an example being the familiar "Belisha Beacon." Display stands for shop windows are made in a similar manner.

Laminated plastics sheet, as referred to previously, can be "post-formed" to relatively simple shapes in a similar manner. Although theoretically they are thermosetting resins, on heating there is sufficient thermoplasticity in the material to enable it to take the shape under the action of heat, but with very little pressure. Using special resins, laminating at pressures as low as 10 lb. per square inch can be carried out by the "rubber-bag" process. The impregnated plies are wrapped round a former, and the whole is kept in position by means of a rubber membrane from which air is exhausted. This can then be heated in some form of chamber which cures the resin. In this way articles such as suit-cases and some as large as small dinghies have been made.

This has been only a very brief survey of general methods employed in fabricating and manipulating plastics materials. New techniques and improvements on old ones are constantly being worked out in this rapidly expanding industry.

H. M. D.

METAL DEGREASING BY TRICHLORETHYLENE

THE removal of grease and oil from metal is essential in practically every factory and workshop in which metal is processed. Degreasing exposes the base surface for repair, inspection, or for the application of a corrosion-preventing process. It is also called for where the temperature of a subsequent process would burn the oil on the metal and spoil its surface, or even affect its composition.

Methods of Removal

The removal of grease can be carried out in several ways, and a few of the various methods are mentioned here:

(*a*) By washing in any alkaline solution, followed by two additional processes consisting of a thorough swilling in clean water and drying out.

(*b*) Another method is burning off the grease in a furnace, but is not generally used nowadays except for certain classes of work before vitreous enamelling.

(*c*) The removal of grease by dissolving it in solvents is by far the easiest and quickest method yet devised, and with the advent of the non-inflammable chlorinated hydrocarbon type an efficient and safe process has been made possible.

(*d*) Modern methods employ the non-inflammable chlorinated hydrocarbon trichlorethylene, which is one of the most powerful grease solvents known and is ideal for metal degreasing. When boiled, it gives off a clear vapour four and a half times as heavy as air, and does not attack the common metals. Work degreased in suitable plants with this solvent leaves the process in a dry, neutral condition.

DEGREASING PLANTS

An extensive range of plants has been developed to utilise the outstanding properties of trichlorethylene; the three main types are vapour, liquor, and liquor-vapour.

Vapour

This plant consists of a tank in which a small quantity of trichlorethylene is boiled, filling the tank with solvent vapour up to a bank of condensing coils

near the top. The solvent condenses on an article suspended in the tank and dissolves any oil or grease, which falls into the sump. This action continues until the article being cleaned reaches the temperature of the vapour, by which time all traces of grease will have been washed off.

The solvent can be recovered from the grease and oil which accumulate in the sump by distillation in the plant itself.

Liquor

This plant also consists of a tank, the lower half of which may have one, two, or more compartments containing boiling trichlorethylene, and again, a bank of condensing coils at the top to prevent the escape of solvent vapour. The condensate is returned to the last compartment.

An article to be degreased is immersed in the various compartments in succession, receiving a final washing in clean solvent condensate in the last compartment. The grease and oil gradually accumulate in a special concentration compartment, or a still.

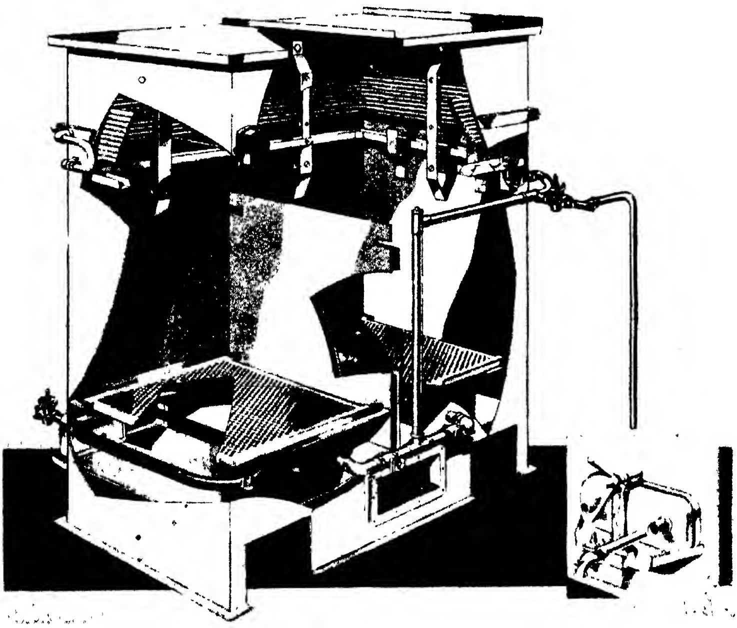


FIG. 1.—LIQUOR-VAPOUR PLANT—STEAM HEATED
(*Inset*) Quick-release cleaning door.

Liquor-vapour

The liquor-vapour plant combines washing in boiling solvent with degreasing in vapour.

CHOICE OF PLANT

In most cases vapour degreasing will meet all requirements except for the following instances, where liquor or liquor-vapour degreasing is necessary.

It will be found that when solid materials are held in suspension, vapour degreasing removes the grease bond, but leaves the solid adhering to the work. This can be overcome by immersion in briskly boiling solvent liquor, which removes the powder as fast as the dissolving grease releases it. The grease, of course, dirties the solvent, and if a perfectly clean surface is imperative, vapour treatment is necessary after the liquor wash, and therefore the liquor-vapour process is recommended.

When the work is very light, it reaches the temperature of the vapour before sufficient solvent has condensed to remove all oil. Therefore, it is an advantage to treat such a work first in liquor and then in vapour, and a liquor-vapour plant is the most suitable.

Flat articles can only be degreased by vapour when they are separated in racks; but basket-loads of such parts, all stuck together with oil, are easily degreased in liquor. The solvent film left between such parts is recovered by draining off in a cold draining compartment.

SPECIAL PLANTS

Every degreasing problem cannot be solved by the standard range of plants; therefore, a few of the special classes are discussed below.

Continuous Vapour Plants

Such plants can be designed to degrease work as it passes along a conveyor.

Continuous Liquor-vapour Plants

When dirt and metal particles have to be removed as well as oil and grease, these plants are used. The articles are passed along a conveyor mechanism through a bath of vigorously boiling solvent before the final vapour treatment.

Continuous Jet Plants

Sometimes it is necessary for the work to be scoured clean by jets of solvent pumped on to it at high pressure from all angles. The jetting compartment in these special plants is suitably luted on either side to prevent the escape of any sprayed solvent into the atmosphere. After jetting, the articles pass through a final vapour compartment and emerge from the plant clean and dry.

Continuous Strip Plants

These are used to degrease heavy bright strip after rolling and before annealing, and also to clean light strip running at a relatively high speed before finishing processes.

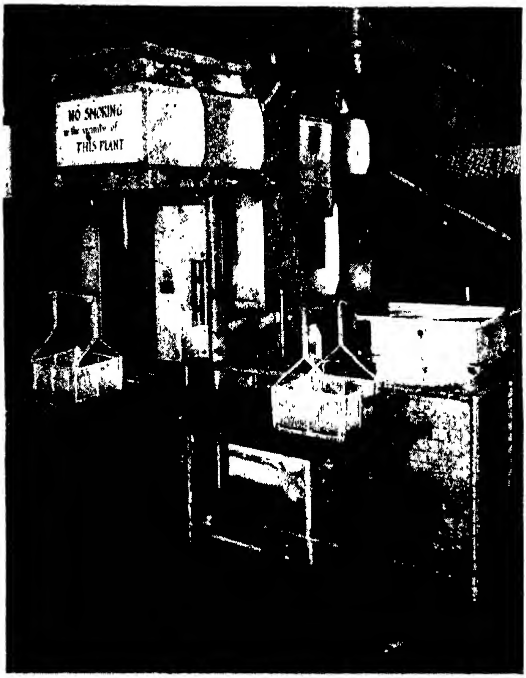


FIG. 2.—CONTINUOUS VAPOUR PLANT FOR DEGREASING SMALL ARTICLES

Such plants can be designed to degrease work as it passes along a conveyor or they can form the first unit of a plant in which one conveyor takes the work to several subsequent processes.

Plants for Long Narrow Objects

These are usually of the vapour type, and are occasionally provided with an auxiliary tank which collects pure solvent distillate. This solvent can be pumped through a flexible pipe fitted with a long nozzle and directed on the work.

Sheet-metal Plants

This plant is of the vapour or liquor type according to requirements. Liquor treatment is to be recommended where solids, such as polishing compounds, have to be removed, for it gives a cleaner finish and can be more economical in operation.

Rotary Plants.

Certain classes of work tend to cup solvent, and large batches of small closely lying parts retain oily solvent in the centre of the mass. Plants are therefore made in which the work is revolved in cylindrical wire baskets during degreasing. Vapour or liquor treatment or an alternation of both can be arranged, and the plants can be either hand or mechanically operated.

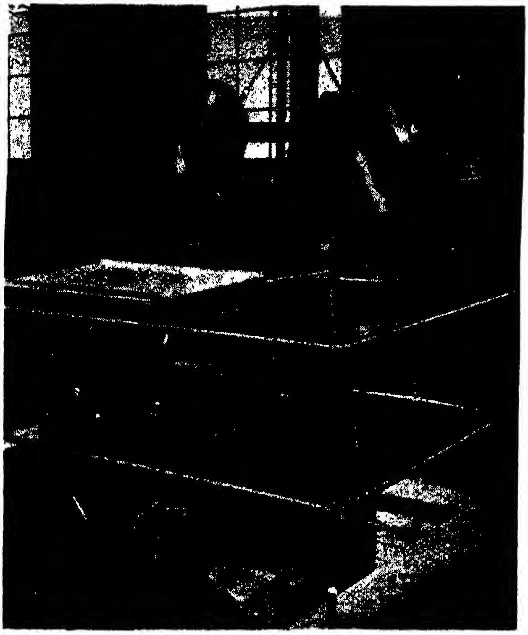


FIG. 3.—SPECIAL VAPOUR PLANT

The plant illustrated is fitted with a pumping attachment for degreasing automobile assemblies during reconditioning and overhaul.

METHODS OF HEATING AND SAFETY CONTROL DEVICES

Various methods of heating are employed to suit the particular application of the plant, and degreasers incorporating gas, steam, high-pressure hot water, electrical, or oil heaters are available.

Gas Heating

It is important, with this type of heating, to see that the gas main is large enough, for excessive pressure drop in the pipes, due to small diameter, elbows, etc., is certain to cause trouble. If a burner is starved of gas, the plant cannot give the satisfactory results which were obtained on test by the manufacturers.

There should be an even blue flame throughout the length of the burner, although there may be some reduction at the end of very long burners. The flame should touch the base of the plant, and if any yellow persists with the air control fully open, the gas injector is in need of adjustment.

The gas supply to the burners is normally connected to two thermostats, one at the top of the plant and the other in the sump. The top one will cut down the gas to a small pilot flame if the vapour level rises too high, and similarly the bottom one will cut off the gas supply to the plant if the temperature of the liquor in the sump rises above 120° C.

It is very important that the sump thermostat should be covered with solvent, as heating above 120° C. will decompose some of the solvent and the acid formed will attack the plant.

Steam Heating

The steam supply should be dry, saturated, unsuperheated, and at a pressure not exceeding 30 lb. per square inch. Supplies over this pressure can give rise to dangerous conditions, as the vapour generated may not be controlled by the condensing coils, and it is necessary to fit a reducing valve.

Dirt must not be allowed to become baked on the heating coils, for it will reduce heat transfer and lower the plant output. The steam coils must always be covered with trichlorethylene.

Most plants are fitted with a safety device which automatically cuts off the steam if the water supply fails or becomes inadequate.

High-pressure Hot-water Heating

Where this method is used, heat input is regulated by orifice plates or by stop valves with adjustable orifices fitted in the connections to the heating coils.

Dirt must not be allowed to become baked on the heating coils because, as with steam heating, the heat transfer will be affected and the plant output reduced. The hot-water coils must always be covered with trichlorethylene.

A thermostat near the top of the plant operates a magnetic valve which cuts off the heat supply if the vapour level rises too high.

Electricity

In this case heating elements are fitted beneath the sump, and switch gear enables varying heat inputs to be supplied according to the degreasing load. Immersion heaters may be used as an alternative. Thermostats at the top and in the sump cut off the heat input if the vapour level rises too high, or the temperature of the sump liquor rises above 120° C.

Fuel Oil or Paraffin Heating

A burner has been standardised for plants heated by paraffin or other fuels; it requires no independent compressed-air supply, and the heat input is thermostatically controlled.

Thermostats

All thermostats are tested, set, and normally sealed in position. Should a thermostat be damaged in any way, it must be reported immediately to the manufacturers of the plant, as failure to do so may cause damage to the plant or may be considered neglect of a safety precaution.

PLANT INSTALLATION

The plant should be installed in a well-ventilated position free from direct draughts; attention to ventilation will prevent unpleasant symptoms, such as drowsiness and sickness. When plants are placed over pits of over 18 in. depth, the pit must be specially ventilated.

To protect wooden floors from heat radiated from the bottom of gas-heated plants, a steel plate should be placed immediately beneath the plant, with an air space between it, and a heat-insulating sheet placed on the floor.

A suitable slow-moving check-action hoist is essential for efficient operation of larger plants taking heavier loads of work.

With gas-heated models, it is strongly recommended that the burnt-gas outlets be taken outside the building by means of a flue fitted with a cowl to prevent any down-draughts.

With steam-heated plants a steam-pressure gauge and operating valve should be fitted close to the plant.

WATER IN THE PLANT

Water can get into a plant from several sources, for example from cylinder-head water jackets, water-soluble cutting oil from machined parts, or condensation from the atmosphere.

Water in a plant can result in the staining of the work, and will, in the course of time, cause corrosion both of the plant and the work; its removal should be arranged directly it is detected, and water separators can be fitted for the continuous removal of water from degreasing plants.

Cooling Coils

If a cooling coil is at fault, water will be seen floating on the solvent in the distillate trough and the sump. Plants having steel cooling coils may be affected in this respect, as the water in certain areas is sufficiently corrosive to produce pinholes in the coils. When they start to leak, new copper replacements should be fitted.

Atmospheric Moisture

Water from atmospheric sources can be greatly reduced and sometimes entirely avoided by adjusting the cooling water flow so that the exit water is tepid.

OPERATING PRECAUTIONS

As with most organic solvents, the vapour of trichlorethylene, if inhaled in sufficient quantity, can cause drowsiness or even unconsciousness.

The following precautions should therefore be observed when handling this solvent or operating trichlorethylene degreasers:

(*a*) Avoid breathing the vapour.

(*b*) Do not use the solvent in any place which is not well ventilated.

(*c*) Do not lean into plants to operate them.

(*d*) Do not enter a plant or pit unless wearing an approved breathing apparatus and a life-line, and having someone in attendance.

(*e*) Never rush work through a plant. This will cause an unpleasant and unnecessary diffusion of vapour into the atmosphere.

(*f*) Operators should never be allowed to overwork plants.

(*g*) Take intelligent care when scraping sludge through mud doors.

Trichlorethylene should not be allowed to come into too frequent contact with the skin, as it removes natural body grease, leaving the skin dry and tender and liable to crack. Operatives working with solvents and liable to contact with them should treat the skin before and after work with some preparation such as Lanoline.

Trichlorethylene undergoes a fundamental change when subjected to very high temperatures, such as naked lights and red-hot surfaces, traces of injurious gases being formed. *As a precautionary measure, smoking should not be permitted where such solvents are in use.* Naked lights should be avoided, unless provided with a flue to carry away the products of combustion.

The manufacturers of degreasing plant usually supply a suitable precaution card which should be displayed near it.

We are indebted to Imperial Chemical Industries, Ltd., for supplying the information upon which this article is based.

E. M.

THE SODIUM HYDRIDE PROCESS OF DESCALING

SODIUM hydride is a powerful reducing agent. About 2 per cent. in a bath of molten caustic soda reacts with oxides present on metal in the form of scale, and reduces them to a finely divided metal powder, or sometimes to a loosely adhering flaky foil.

Chromium oxide is the only known exception to this rule, being reduced to a lower oxide. This also adheres loosely, however, and can easily be removed.

Sodium hydride is not supplied as such, but is generated in the plant by a reaction between hydrogen in the form of cracked ammonia and sodium.

The sodium hydride process easily removes hot rolling, annealing, and heat-treatment scale from most ferrous and non-ferrous metals. Wire is completely cleaned of soap and similar drawing lubricants, leaving it suitable for bright annealing, without risk of staining. Iron and steel castings are entirely cleared of foundry sand, even in the most intricate internal cavities, which are difficult to reach by any other means.

This process can be applied to all metals, except those with low melting-points, and those—such as zinc, tin, aluminium, and their alloys—which are readily attacked by caustic soda. A typical sodium hydride plant is illustrated in Fig. 1.

Advantages of the Sodium Hydride Method

Descaling by this process has the following advantages:

(1) The treated metal is unaffected. Unlike acid pickling, the sodium hydride process attacks the scale and not the underlying metal. This means that the metal cannot be over-pickled, and results in appreciable savings when processing expensive alloys.

(2) The process is rapid. Once the metal reaches the temperature of the descaling bath, the scale is reduced very rapidly—usually within one minute. For example, the total immersion time for coils of rod weighing approximately 1 cwt. is only about 10 minutes. This can be appreciably reduced by preheating the coils to 350° C.

(3) There are virtually no corrosion problems. The metal under treatment is not affected, and the plant itself may be constructed of mild steel, and has a long life. The hydride generator is slowly attacked, but it can be easily and cheaply replaced at intervals of about a year or more. There are no corrosive fumes to damage the fabric of the building or endanger the health of operators.

(4) The same bath suits all metals. The same reagent descales all metals to

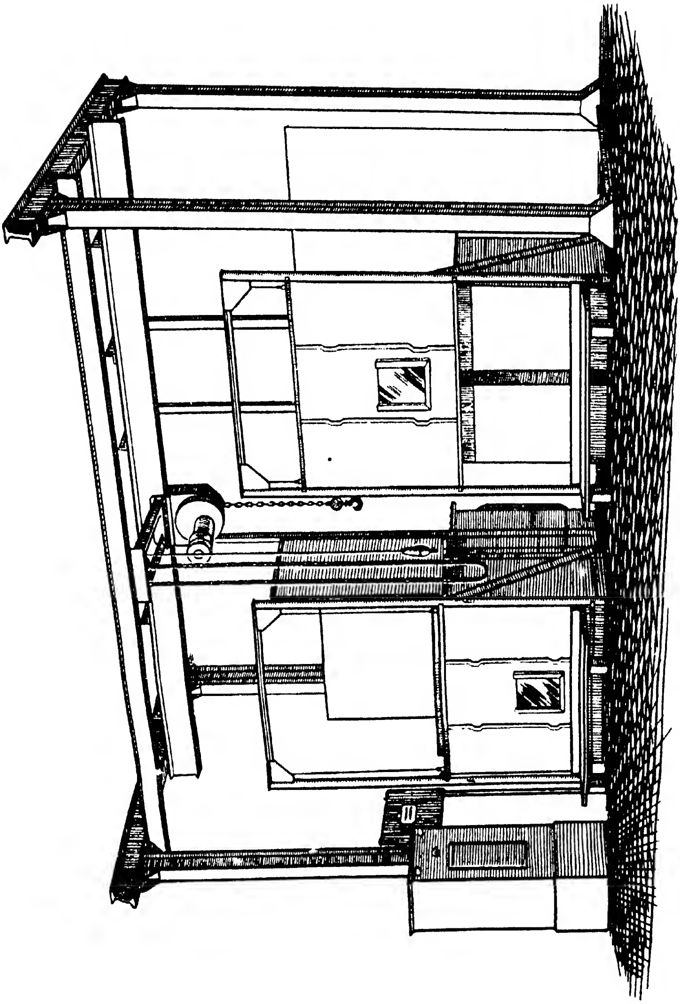


FIG. 1.—SODIUM HYDRIDE PLANT WITH COLD-WATER QUENCH AND HOT-WATER RINSE TANKS

which the process is applicable. Separate baths of different solutions are therefore unnecessary.

(5) Hydrogen embrittlement is impossible. The metal while under treatment cannot absorb hydrogen and so become embrittled. On the contrary, the tendency is to drive off any hydrogen present in the metal.

(6) The reagent penetrates deeply. The reagent is very fluid and penetrates into minute interstices. For example, coils of wire rod can be descaled throughout without removing their binding wires.

(7) Disposal of waste is simple. As the reagent is alkaline, and readily soluble in water, disposal of waste is easy and does not present the serious problems associated with acids.

Operation

Descaling is carried out in the following manner:

The metal, which may be suspended from hooks, slung from a chain, or placed in a basket of strong wire mesh, is immersed in the bath of caustic soda containing sodium hydride, for slightly longer than it takes to attain the same temperature as the bath—i.e. 350–370° C. It is often advantageous to preheat the metal, as this ensures that it is completely dry, and reduces the immersion time to a minimum.

It is then taken out, allowed to drain for a minute or two, and quenched in cold water. The steam generated by this operation usually removes most of the reduced scale from the surface of the metal. Any still adhering can be washed off by means of a high-pressure water jet or similar means. A final swill in hot water cleans away the last traces of caustic soda, and aids rapid drying.

With stainless steels and other alloys, when a bright finish is required, one of the normal acid dips for brightening may be applied after water quenching (e.g. 10 per cent. nitric acid, with or without 1–2 per cent. of hydrofluoric acid, at about 65° C.—immersion time, ½–1 minute, followed by swilling in hot water).

PLANT

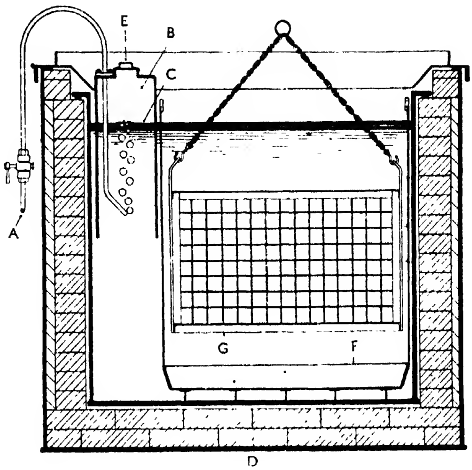
The caustic soda/sodium hydride bath is an electric arc-welded tank of mild steel. The corners of such vessels must be prepared in such a way that full penetration of sound weld metal is assured. After all welding operations have been completed, the vessel should be stress-relieved. This is accomplished by heating in a muffle furnace to 650° C., and then allowing to cool in still air. This treatment ensures that there will be no trouble at a later stage due to caustic embrittlement.

Although the caustic soda may be heated in various ways, depending on the available facilities, electrical heating by external resistance heaters is the most satisfactory.

Baths should be insulated against heat losses. A welded mild-steel casing outside the insulation will not only protect it against damage, but also act as a container in the unlikely event of the bath developing a leak.

FIG. 2.—CAUSTIC SODA/SODIUM HYDRIDE BATH

A. Cracker gas pipe.
B. Sodium hydride generator.
C. Molten sodium layer.
D. Insulating brickwork.
E. Sodium charging lid.
F. Sludge tray.
G. Work basket.



Generator

The sodium hydride generator consists of a welded mild-steel box, open at the bottom, with a hole at the top large enough to admit blocks of sodium, and covered by a lid. This box is immersed in the caustic soda for a depth of 12–15 in., projecting about 6 in. above it. One or more mild-steel tubes pass through the top of the generator box, and are carried about 9 in. below the liquid level. These serve to introduce the cracked ammonia, which bubbles up through the caustic soda and meets the layer of molten sodium floating on the surface inside the generator.

For a small bath containing 1–2 tons of caustic soda, one generator is sufficient, but two or more may be required for larger plants.

One ammonia cracker is needed for each hydride generator. These are fed from cylinders of anhydrous ammonia. The cracked ammonia is piped to the hydride generators.

Sodium, in the form of dry blocks, is fed into the hydride generators at intervals determined by the size of the plant and the amount of work passing through it.

To conserve heat when the plant is not in use, the bath is fitted with an insulated lid, which is lifted off when not required.

If the plant is in continuous operation, a small amount of sludge may accumulate. This can easily be removed if a sludge tray made of mild-steel sheet, and perforated with holes ¼ in. diameter, is kept in the bottom of the tank, and occasionally lifted out and cleaned. It must be carefully dried before replacing. A better plan is to have two sludge trays for alternate use.

Starting and Operating the Plant

The bath of molten caustic soda is prepared by melting flake caustic soda, and heating it to 350–370° C., the temperature being controlled by means of a thermocouple and automatic regulator. The actual procedure for starting up in any particular case depends on the method of heating adopted, and the plant manufacturer should be consulted on this matter. The level of the caustic soda should be about 6 in. below the top of the tank, and it may be necessary occasionally to pump or bale out any excess into a dry container.

Starting the Hydride Generator

To start up the hydride generator, remove the charging cover and insert one brick of sodium, leaving the cover off. Allow the sodium to burn until all the air in the generator box is used up—as shown by the extinction of a torch plunged into it—and then replace the cover. Next, relight the torch, place it near the sodium charge hole, and turn on the hydrogen (cracked ammonia) until the escaping gas ignites at the charge cover. Adjust the gas flow to 60–100 cub. ft. per hour, and charge the sodium to the generator at the rate of about 5 lb. per hour. A higher charging rate up to a maximum of 10 lb. per hour and a corresponding gas flow may be used when bringing the hydride content of the bath up to 2 per cent. after a shut-down.

To charge sodium, remove the charge cover, and ignite the gas with the torch which is always kept alight over the cover. Add sodium and replace the cover.

Shutting Down the Generator

To shut down the generator, stop charging sodium, and let the gas continue to flow for a further two hours or until no sodium remains in the generator. Then turn off the gas.

Intermittent Use of the Plant

Continuous operation gives the most economical results, but when day-work alone is preferred, or the plant is not in use during week-ends, its temperature should be lowered to 325° C., and a floating lid, made of mild steel in the form of a tray, put on the molten caustic soda to reduce its exposed area. In addition, the tank should be covered with an insulating lid to minimise heat loss.

If the plant is to be out of action for long periods, the bath may be allowed to solidify, after which the caustic soda should be covered with a layer 1 in. thick of light sodium carbonate.

SAFETY PRECAUTIONS

The main stock of sodium should be kept under lock and key in a store that contains no possible source of water or steam, or any combustible material, such as straw, paper or shavings. Sufficient sodium for immediate requirements —normally, one drum—may be kept near the descaling plant so long as it is protected from water. The pieces should be handled with dry metal tongs.

The molten caustic-soda bath and the water-quenching tank should be screened both from the operators and from one another.

Protective clothing should be worn. Cotton moleskin gloves are more comfortable than rubber, and provide a good measure of protection. Woollen material is quite useless. Protection to the eyes should be afforded by close-fitting goggles, which should be worn whenever there is a risk of caustic soda being splashed, and also when sodium is being handled. An asbestos mask fitted with a mica eyepiece will shield the face, and its use when making sodium additions is strongly recommended.

Treatment of Injuries

In case of accidents, a liberal supply of dry sand or dry sodium carbonate should be available for dealing with sodium fires.

A 5-gallon aspirator of ammonium chloride solution (5 per cent.) should always be close at hand, so that any part of the body or clothing on which caustic soda has splashed may be immediately flooded with this neutralising solution.

If caustic liquor enters the eye, the following procedure must be followed without delay:

The eye must be washed immediately with 5 per cent. ammonium chloride solution. This should be stored in an 8–16 oz. eyewash bottle kept in a conspicuous place. The treatment should be carried out on the spot, and the operator then removed to the works surgery, or any other convenient place, and the eye irrigated continuously for one hour with running lotion—either "normal saline" or boracic lotion—taking special care that the lotion reaches the corners and lower sulcus. This prolonged irrigation is extremely important and must be done at once. If the case is sent to hospital without this, irreparable damage will have been done.

Sodium burns should be similarly treated, after any particles of sodium adhering to the skin have been removed.

We are indebted to Imperial Chemical Industries, Ltd., for supplying the information upon which this article is based.

E. M.

DE-ENAMELLING BY CAUSTIC SODA

DE-ENAMELLING is a most useful process for reclaiming valuable production material rejected for enamelling defects and also for the removal of enamel in the reconditioning of used articles.

One of the most effective agents for this purpose is caustic soda, which may be used in the molten state or as a solution, the former method being the most efficient when dealing with the modern highly resistant enamels.

MOLTEN CAUSTIC SODA PROCESS

With this method the normal types of enamel can be removed in approximately two minutes, the more resistant ones taking rather longer, but seldom more than ten minutes.

The bath of molten caustic soda is maintained at a working temperature of between 430–530° C., and the articles to be treated are suspended in the liquid by means of racks or hooks for the necessary length of time required for the complete removal of the enamel.

With articles not liable to distortion, the higher temperature is to be preferred, as the action is more rapid. Spacing between articles should be in the region of 3–4 in. to allow the caustic to reach all surfaces.

After removal from the bath, the articles are drained, allowed to cool down to room temperature, and then well washed in hot water to remove all traces of caustic soda. Any remaining enamel sludge may be removed by brushing lightly under running water.

Design and Construction of the Plant

A suitable bath can be constructed from ¾-in. to 1¼-in. thick mild-steel plate, the thickness depending upon the size required, and bearing in mind that the strength of mild steel is reduced at 500° C.

Corners and joints of the vessel should be prepared so that full penetration of sound weld metal is assured, as shown in Fig. 2.

After welding the bath should be stress-relieved.

A sludge tray is placed in the bottom of the bath.

Heating Equipment

The use of external resistance heating elements is the most favoured method of heating, but electric immersion heaters are also used. They are suspended

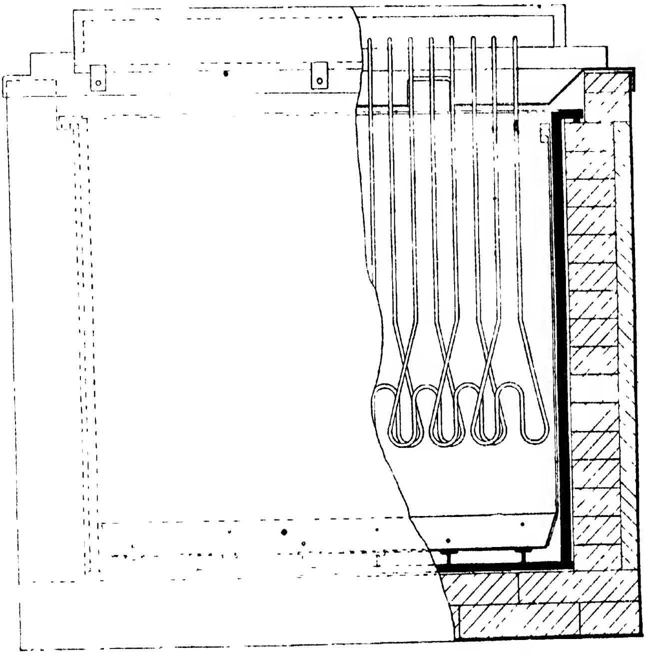


FIG. 1.—FUSED CAUSTIC SODA DE-ENAMELLING BATH

round the sides of the bath, and kept well clear of the bottom, so that there is no danger of them becoming embedded in sludge. External gas firing is also permissible, but flame impingement on the sides of the bath must be avoided. A normal heat insulation covering should be applied to the outside of the bath.

Sludge Removal

The operation of the bath is slowed down by the accumulation of sludge after the melt has been in continuous use for several hours, and de-sludging becomes necessary. This is carried out by removing the sludge tray, in which the sludge has accumulated, and replacing it by an empty one. Made-up caustic soda is then added, and the temperature of the bath allowed to fall to 350–380° C. to precipitate some of the dissolved enamel. The temperature is then raised again to working heat. De-sludging is usually required daily.

THE CAUSTIC-SODA SOLUTION METHOD

A solution of not more than 50 per cent. concentration is used, and the temperature of the operation is at, or just below, boiling-point, i.e. approxi-

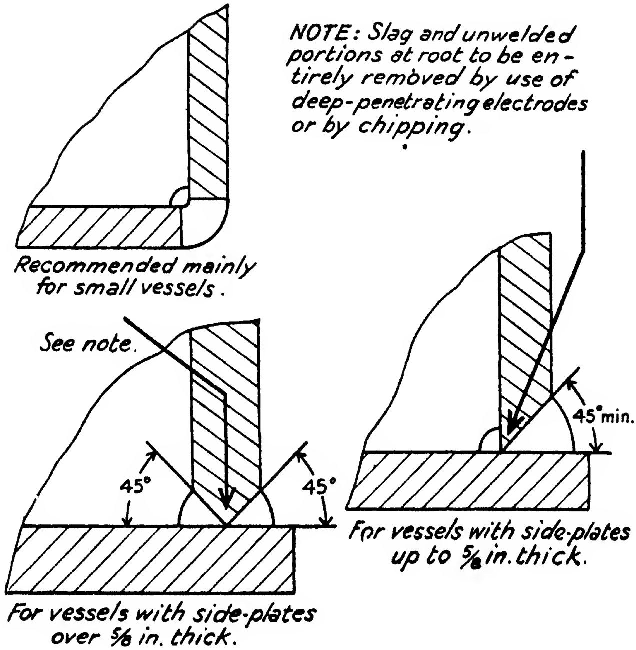


FIG. 2.—RECOMMENDED CORNER WELDS FOR CAUSTIC SODA TANKS

mately 140° C. The time of immersion varies according to the class of enamel, usually from 4 to 12 hours.

Once the solution has been made up in the correct strength, no further additions of caustic soda should be made to maintain the concentration. The solution should be used until it will no longer remove the enamel in an economic time, and should then be discarded. The only additions to be made to it during the period of operation are to make up the volume losses due to drag-out and de-sludging.

Design and Construction of Plant

The tank for containing the caustic soda is made of mild steel electrically welded, as in the case of molten caustic soda, but in view of the lower working temperature, it is only necessary to use $\frac{3}{16}$-in. plate. It is again essential that the tank should be stress-relieved after welding operations have finished.

The solution may be heated either internally by electric immersion heaters or externally by electric resistance heaters or gas. In the latter case the bottom and lower sides of the bath should be protected from flame impingement by means of refractory tiles. As before, a sludge tray is employed.

Operating the Bath

De-enamelling should be accomplished in 8–12 hours, and the work should not be allowed to remain still in the solution. Evaporation losses should be made up continuously by means of a trickle of water running into the solution at the corner of the tank.

The loaded crate of work should be lowered into the solution and left with sufficient water input to the bath to compensate for evaporation.

After such time as is found necessary for the particular grade of enamel being treated, the crate is removed and swilled in a water tank. After unloading the crate the individual pieces can be washed and any residue removed by wire brushing or stoning.

De-sludging

With a bath that is in continuous use, it will be found necessary to carry out de-sludging at least once a fortnight.

The bath should be allowed to stand prior to de-sludging, so as to allow all the sludge to settle. The sludge tray should then be gently lifted out and allowed to drain over the bath, after which it should be emptied in a protected place where it can cause no injury to personnel. Flake caustic soda and water equivalent to the required volume of 50 per cent. solution should then be added to the bath and the sludge tray replaced.

Safety Precautions

The caustic-soda bath should be effectively screened so that in the event of a splash the operatives will not be injured. All work should be taken out of the bath by means of lifting tackle operated from the protected side of the screen.

Whilst working in a caustic-soda de-enamelling plant, protective clothing should be worn. Cotton moleskin gloves give protection against dry caustic soda, but woollen material is quite useless. Rubber gloves must be worn to protect against caustic solution. The eyes should be protected by close-fitting goggles.

An aspirator of ammonium chloride solution (5 per cent.) should be at hand so that clothing splashed by caustic soda can be flooded and neutralised at once.

If any solution enters the eye, the following procedure *must* be carried out *at once*. The eye must be bathed with 5 per cent. ammonium chloride solution. The patient should then be removed to the first-aid room, and the infected eye should be irrigated continuously for one hour with running lotion, such as boracic, taking care that it reaches all corners of the eye.

The only satisfactory precaution against eye burns is efficient goggles.

We are indebted to Imperial Chemical Industries, Ltd., for supplying the information upon which this article is based.

E. M.

THE "ROTODIP" PROCESS

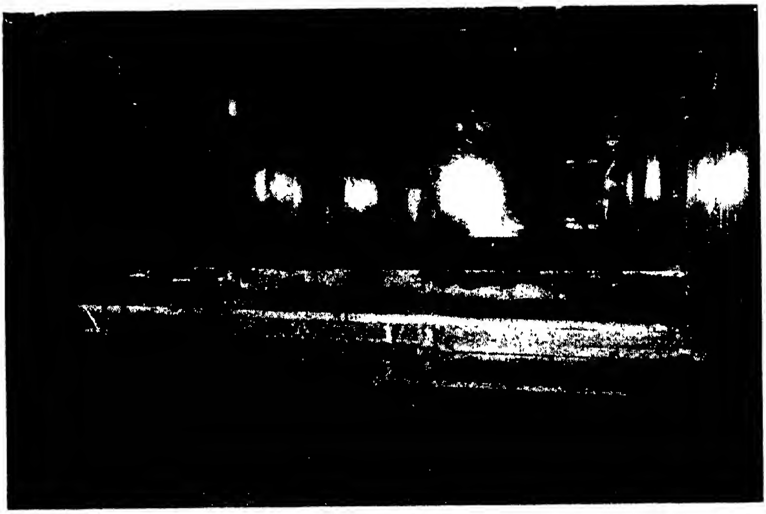


FIG. 1.—GENERAL VIEW OF THE "ROTODIP" PLANT

UNTIL the advent of the new rust-proofing technique, the procedure for finishing car bodies was to clean down the body thoroughly to remove all grease, and then to rinse with clean water by hand or automatic spray, followed by a drying process, after which the primer filler and finish coats of paint were applied by spray gun.

It has long been apparent that the old method, good though it was, did not provide complete protection, because many important parts of the body could not be reached by the mere use of a spray gun once it was assembled.

This problem has now been solved by the invention of a plant known as "Rotodip," which is a trademark of the Carrier Engineering Co., Ltd., coupled with the development of special cleaning and keying solutions called "Bonderite" by the Pyrene Co., Ltd., and paint technique by I.C.I. Ltd.

Bonderising is a development of the well-known Parkerising process which has been in use for many years, and it produces a chemical conversion of the surface of the metal, changing it into a non-metallic phosphate which acts as a protective coating and which is integral with the metal itself.

It thus overcomes the basic difficulties of adhesion which is one of the fundamental difficulties of applied protective coatings, and the fact that the process penetrates into the metal to an appreciable depth prevents the spread of rust by local damage such as scratches.

Under normal conditions, rust attacks the steel in the region of the scratch, and creeps along the surface of the metal under the paint, thus destroying its adhesion and causing it to flake off. In the case of Bonderised steel, the protecting surface layer arrests the surface-spreading of the rust, greatly restricting the extent of the damage which it causes. In addition, the surface damage has to be quite appreciable to expose the virgin metal to the effect of rust.

It has also been demonstrated that the process retards the ageing and development of brittleness of the paint film subsequently applied to it, and it thus ensures longer life to the finish applied to the body.

THE "ROTODIP" PLANT

The anti-rust plant illustrated in Fig. 1 consists of a long metal tunnel divided into a number of separate tanks through which the car bodies pass, to be first of all cleaned and thoroughly rinsed before receiving a Bonderising bath. The action of this solution produces a chemical change on the surface of the metal, rendering it highly rust resisting. The chemically clean, slight etching effect of the process provides a perfect key for the subsequent painting operation.

The bodies enter the plant in the plain-steel, greasy state, and leave some 1¾ hours later, having been cleaned, rust-proofed, and primer painted inside and out, entirely automatically.

For their journey through the plant, the bodies are mounted on a revolving spit, as shown in Fig. 2, with the bonnet, wings, and boot lid in position, but spaced slightly away from the body to allow free circulation during processing. Each body is then carried broadside through the length of the plant on conveyor chains in such a way that it revolves on its own axis while passing through the machine.

The operation of the plant is, of course, continuous, but for explanatory purposes can be considered as consisting of two distinct stages, viz. rust-proofing and primer painting.

Rust-proofing

In this stage there are six large tanks through which the car body is progressed on the revolving spit, the axis of rotation being just above the top edge of the tanks, so that while the part of the body travelling through the lower half of the orbit is immersed, that in the top half is being subjected to spray (Fig. 3). The treatment in these six tanks is as follows:

(1) Cleaning by means of an emulsion or alkali-type cleaner.
(2) Primary rinse with clean cold water after cleaning.
(3) Secondary rinse with clean hot water after cleaning.
(4) Application of Bonderising solution.
(5) Hot-water rinse.
(6) Final rinse with dilute chromic solution.

FIG. 2.—BODY BEING MOUNTED ON A REVOLVING SPIT FOR ITS JOURNEY THROUGH THE "ROTODIP" PLANT

FIG. 3.—BODY RECEIVING ITS ALKALI OR EMULSION CLEANER IN THE "ROTODIP" PLANT

FIG. 4.—BODY GOING THROUGH THE PRIMER TANK

The bodies are now completely cleaned and protected, and pass directly on to the next stage, having been automatically transferred to a second set of traction chains within the machine, but still being mounted on the revolving spit. This second half of the treatment consists of the following operations:

Primer Painting

(1) Completely drying off the body by passing it through an oven.

(2) Cooling down to the correct painting temperature.

(3) Primer painting by revolving body in a large tank containing the primer (Fig. 4).

(4) Draining off surplus primer (for which purpose the speed of rotation is increased temporarily).

(5) Final stoving, prior to leaving the plant.

After this, the bodies go straight on to finish painting, and then to the final assembly line.

THE PAINT FINISHING LINE

When the body shells are received from the "Rotodip," they are mounted on a special trolley with wings, bonnet, and bootlid in place, which enables the operator to revolve them longitudinally with one gloved hand, so that he can reach every part of the body with the spray gun. This process, known as "Rotospray," has also been developed by the Carrier Engineering Co., Ltd.

They then proceed along the half-mile of booths, rubbing bays, and ovens, on a moving conveyor at the rate of twenty an hour, until some seven hours later they emerge with a finish polish which will last the life of the car. During this time they will have undergone some twenty-four operations.

Sequence of Operations

The "nibs" and "runs" (imperfections in the primer finish) are first rubbed down, and then any other irregularities which would prevent proper painting at a later stage are dealt with.

The body is now sprayed with stopper while being rotated on its mounting by the operator, to ensure an even coating all over and that no part of the body is missed.

Bodies then receive their first baking at a temperature of 200° F., following which the stopper is wet-sanded and the body is blown off by compressed air and given a wiping off with petrol. From here they enter the spray booths, and receive the first and second rust-coloured surfacing or filler coats with a short flash-off period between each.

All spraying operations are carried out from one side of the line by rotation of the body on its trolley, the operator working under strip fluorescent lighting, which shows up any flaws in the paint work so that they can be rectified on the spot.

FIG. 5.—WET-SANDING OPERATORS AT WORK, USING THE "SUNSTRAND"

They then pass through another baking oven at a thermostatically controlled temperature of 300° F. This is the maximum temperature used in order to obviate the possibility of melting the stopping. Thirty-five minutes are spent in this oven which, like the subsequent ones through which the bodies pass, is heated by means of oil burners.

Wet Sanding

Wet rubbing is the next process, where mechanical rubbers known as "Sunstrand" machines are used to smooth down the surface coat as illustrated in Fig. 5; the body is then viewed for "orange-peel" effects and oil marks. Better lighting makes the job of the viewers easier, and there is no need for laborious inspection with handlamps, nor does the viewer need to climb up to see whether the roofs are efficiently sprayed and rubbed; one pull of the body which revolves on the trolley can bring any part of the car immediately under his eyes; any faults at this stage are marked on the body with special pencils.

Bodies that have passed through at this stage are washed and dried in ovens and then pass along the booth to have their synthetic ground coat applied. This is stoved in more long ovens at a temperature of 275° F. More wet sandpaper is applied, with the "Sunstrand" machines again used on the roof and flat surfaces to give a smooth finish, and the body is once more viewed, washed, and dried.

FIG. 6.—OPERATORS IN THE FINAL COLOUR BOOTH
Showing the grating through which paint particles are swept to the water below.

FIG. 7.—FINISHED BODY SHELLS LEAVING THE PAINT LINE
They are now ready for the main production lines.

Finishing

The bodies then enter the finishing paint booths, through which 195,000 cub. ft. of water-washed air is passed every minute to eliminate dust before they receive the two final coats.

Compressed air is then used again to blow out the dust from the mouldings.

Using lintless linen soaked in varnish and partially dried, operatives dab and wipe the shells to remove particles of dust and foreign matter which might spoil the final coat. Two sprayings are made with an approximate six-minute flash-off period between each, until the completed body passes into the last oven for its final baking at a temperature of 250° F.

There only remains the touching up of the insides of door frames or under window ledges, which the fast-moving spray may have missed—the application of battery box anti-acid paint, and anti-drum "Bittac" sprayed on to the underside, before the shell is passed out of the shop to the main assembly line.

The plant described is the most advanced painting equipment in existence in the world, and is the result of the pooling of the ideas and resources of four large concerns, each experts in their own particular industrial sphere.

We are indebted to The Nuffield Organisation for the information on which this article is based.

E. M.

HARD FACING WITH "STELLITE"

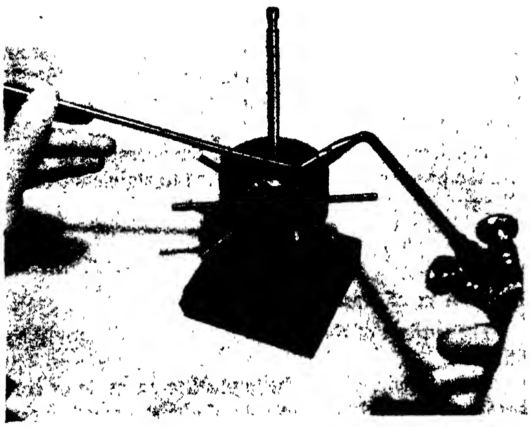
"STELLITE" is an alloy containing cobalt, chromium, tungsten, and molybdenum in varying proportions. It can be heated to a red heat without ever softening. Other characteristics are its low coefficient of friction, ability to take a high polish, high resistance to chemical action and abrasion.

This alloy has many applications, the chief of which are its use as a cutting metal and as a hard-facing rod, hard facing being the process of welding any hard metal capable of resisting abrasion, such as "Stellite," on to the surface of a softer metal, i.e. soft steel.

"Stellite" hard-facing rod is manufactured in three grades—Nos. 1, 12, and 6. Grade No. 1 gives the greatest resistance to abrasion, but as it has a tendency to be brittle, it should not be used where impact is likely to be great. Grade No.12 is softer, and is used to protect large areas where hair-line checks might be detrimental to the service of the part. Grade No. 6 is softer than either Nos. 1

FIG. 1.—"STELLITING" JIG FOR SMALL VALVES

The welding torch should be held so that the excess acetylene flame is directed at an angle of from 30° to 60° to the steel surface.



or 12, but has more ductility, and will withstand fairly severe shocks. It is highly resistant to heat cracking, and is used where a keen cutting edge is desirable.

"Stelliting"

"Stelliting" is the process of hard facing a metal surface with "Stellite" rod by either oxy-acetylene or metallic arc welding.

The oxy-acetylene process is the method whereby a flame resulting from the combustion of oxygen and acetylene gas is directed by means of a blowpipe on to the hard-facing rod, thus melting it and forming a deposit on the base metal, which itself is not melted. This method is the most popular, as it allows the operator better control of the work and produces a smooth deposit.

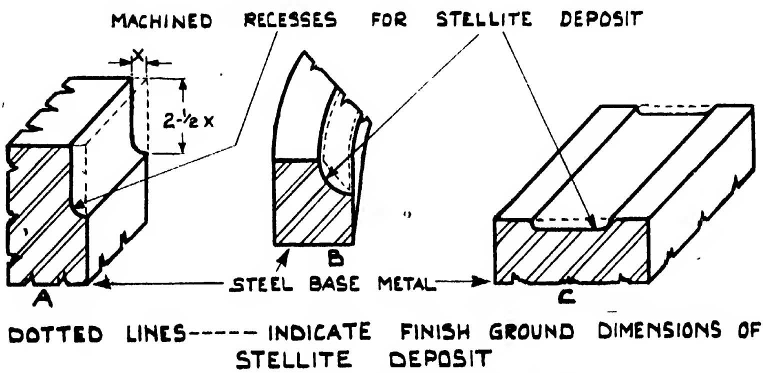


FIG. 2.—METHODS OF PREPARING METAL SURFACES

In the metallic-arc process the "Stellite" rod is made an electrode, and is melted by means of an electric arc struck between it and the metal being hard-faced. This method is preferred for depositing "Stellite" on manganese steel, and can also be employed on large equipment, where the deposit can be used without finishing.

The details given below are for the operation of "Stelliting" on a steel surface, and the process may also be applied to stainless steel, cast iron and nickel-base alloys.

THE OXY-ACETYLENE METHOD

Preparation of Base Metal

The surface of the part to be "Stellited" should be cleaned by grinding or filing.

If the "Stellite" is to be applied to an angle or corner which is likely to be subjected to shock, the steel should be machined as shown in *A* (Fig. 2). Where

no severe impact is to be encountered, the angles or corners may be machined as in *B*. In the event of the alloy being applied to a longitudinal area, the part should be grooved with radii equal to the depth of the grooves as shown in *C*. It will be noted that all corners are rounded, and this practice should always be followed to reduce any tendency to melt the base metal and contaminate the "Stellite." Articles to be finish ground should be made slightly oversize to allow for any scaling or distortion.

The Blowpipe

A standard oxy-acetylene blowpipe may be used, but it is important to select the proper tip size for the job. The correct size can be found by choosing

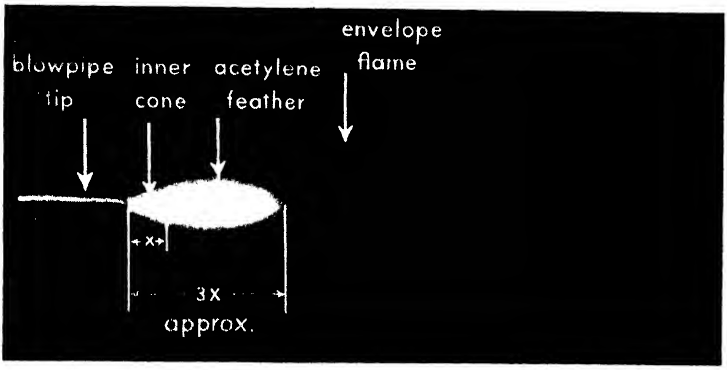


FIG. 3.—CORRECT "STELLITING" FLAME, SHOWING EXCESS ACETYLENE FEATHER

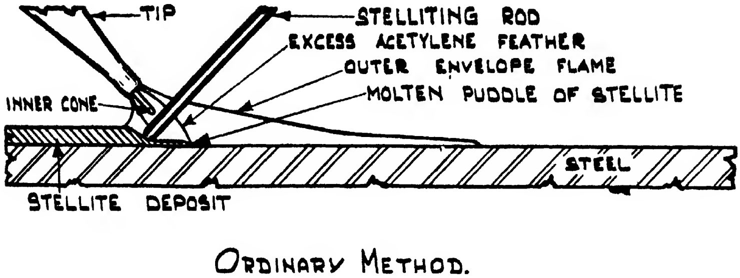
a tip with its orifice one size larger than would be used for steel-welding operations on the part.

The correct flame for "Stelliting" should contain an excess of acetylene, and therefore the oxygen valve on the blowpipe should be turned back. The total length of the excess acetylene feather, when measured from the orifice of the tip, should be about three times as long as the inner cone (see Fig. 3). This excess acetylene flame prepares the steel surface by causing a thin surface layer to melt, giving the steel a watery, glazed appearance known as "sweating." If an excess acetylene flame is not used, the deposited metal tends to pile up and become porous instead of spreading freely.

Preheating

Preheating is necessary for three reasons:

(1) To enable a cooler depositing flame to be used and thus reduce the tendency to melt the base metal.



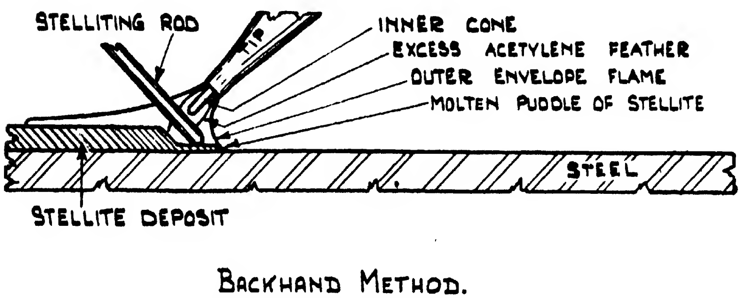


FIG. 4.—METHODS OF DEPOSITING "STELLITE" ON STEEL

(2) To reduce stresses and warping of the base metal (and possible cracking of alloy steels).

(3) To prevent cracks in the "Stellite" deposit.

Small jobs are preheated with the torch almost to a red heat, and larger jobs should be heated with a gas burner or in a furnace or hearth to a similar temperature. The heat must be retained whilst depositing by surrounding the part with bricks or asbestos sheet.

Depositing the Metal

The welding torch should be held so that the flame is directed at an angle of from 30° to 60° to the steel surface. The tip of the inner cone of the flame should be about $\frac{1}{8}$ in. from the steel. The torch is held in this position until the steel has a "sweating" appearance. The flame should then be withdrawn just enough so that the end of the rod can be brought between the inner cone of the flame and the hot steel. The tip of the inner cone should just touch the rod, which should be lightly touching the sweating area. If the first drops of the deposit

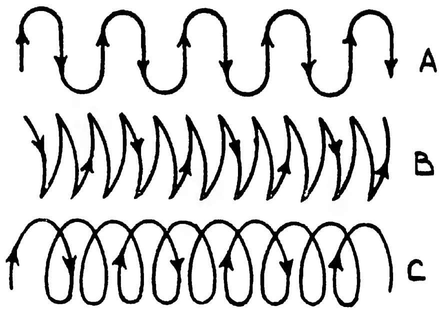


FIG. 5.—MOTION OF THE ELECTRODE TO BE FOLLOWED: (*A*) FOR THIN BEADS; (*B*) FOR HEAVY BEADS; (*C*) WHEN STEEL IS HOT FROM PREHEATING

foam, bubble, or do not spread uniformly, the steel is too cold and should again be brought to the "sweating" condition. The formation of blowholes in the deposit indicates that there is not enough acetylene in the flame, whilst if the pool is surrounded by an excess coating of carbon, too much acetylene is being used.

The molten deposit is spread over the area by removing the rod from the flame and directing the flame into the puddle. The rod is returned to the flame to melt off more "Stellite" as required. Next, the flame should be directed so that a part of it plays only on the edge of the puddle to keep it molten and part on the steel surface adjoining it. As the steel reaches the "sweating" temperature the molten "Stellite" will spread over it. Whilst it is spreading the rod should be brought into the flame again and, with the end of the rod touching the pool, more of the deposit is melted into it. This operation is continued until the desired area is coated. The necessary amount of "Stellite" can be added to make the deposit the desired thickness, but when a thickness of more than $\frac{1}{8}$ in. is required, the operator should go back over the job and add a second layer.

The pool of molten deposit should always be steered in the desired direction by means of the flame and not by stirring with the rod. Usually the work progresses towards the hand holding the rod, but on steel which scales badly or on very thin sections, the backhand method may be used. In this method the work progresses towards the hand holding the welding torch. The two methods are illustrated in Fig. 4.

Cooling

When the deposit is at the required size and thickness the flame should be slowly removed from the pool. If cracks or holes are noticeable, the deposit should be remelted in their vicinity, but if the holes persist, it may be necessary to grind off the deposit at this spot and then add new "Stellite."

On completion of the operation the part should be placed in a box of powdered mica, slaked lime, sand or other insulating material so that it will cool slowly. Slow cooling is necessary to produce a deposit free from cracks and

internal stresses. Articles which show a tendency to crack, as in cases when the deposit is large in area or circular, should be placed in a heat-treating furnace whilst still hot, brought slowly to a low red heat, about 1150° F., and then allowed to cool.

THE METALLIC ARC PROCESS

Preparation of the Base Metal

"Stellite" may be deposited by the metallic arc method on to a surface which is not entirely clean, but, if possible, the part should be cleaned until it is bright, and all corners and projections should be rounded in the same manner as for the oxy-acetylene method.

If the deposit is to be free from cracks it will be necessary to preheat the steel. Articles can be preheated in a temporary brick furnace, open at the top, and should be heated slowly to a barely visible red heat.

Depositing the "Stellite"

The "Stellite" rod can be melted by means of either an A.C. or D.C. arc, and the correct current values for use with each size of rod are given in Table 1. However, with either A.C. or D.C., the "Stelliting" operation remains the same.

TABLE 1.—RECOMMENDED CURRENT FOR ARC "STELLITING"

Diameter of Rod	*D.C.*	*A.C.*
in.	*amps.*	*amps.*
$\frac{1}{8}$	65–100	125–175
$\frac{3}{16}$	125–150	225–250
$\frac{1}{4}$	175–200	250–275
$\frac{5}{16}$	225–250	300–325

A flux-coated rod must be used in preference to a bare rod, as it gives a smoother and flatter bead. It is essential for the flux coating to be perfectly dry, and this may be ensured by shorting the rod to earth to heat it and dry out the coating when necessary.

The electrode should be held in a vertical position close to but not touching the steel, so that when the current is switched on an arc will be struck between them. The arc is then drawn out to a length of about $\frac{3}{16}$ in. when using a $\frac{1}{4}$-in. rod, and the electrode moved over the surface to be covered with a swinging motion as wide as the desired bead.

Fig. 5 shows the motion of the electrode to be followed for thin beads (*A*), heavy beads (*B*), and when the steel is hot from preheating (*C*). Each bead should be applied so that its edge tapers into the surface and is not rounded.

When the width of deposit required is greater than that possible or desirable to obtain with a single bead, the second bead should overlap the first by about

one-third. The first bead should be cleaned by scratch brushing and chipping to remove scale before commencing the second bead. The scale is easily removed when the deposit is cool.

If a second layer of "Stellite" is required, each of the beads in the second layer should cover the line of fusion between two of the beads below. The parallel beads in the second layer should overlap each other by one-third in the same manner as the beads in the first layer.

Cooling

Usually it is not necessary to pay close attention to the cooling of parts "Stellited" by this process, but in cases where cracks might result from too rapid cooling, it is advisable to bury the part, after hard facing, in some insulating material such as slaked lime or sand.

We are indebted to Deloro Stellite, Ltd., for the information upon which this article is based.

E. M.

RIVETS AND RIVETING

THE manufacture of a modern rivet is strictly controlled to conform to various specifications and shapes, according to the particular requirements of the finished structure, whether it is a high-pressure vessel or a multiple-story building.

All rivets must be of ductile steel, made from selected material by the open-hearth process, of good quality, free from cracks, surface flaws, or other defects. The tensile breaking strength should be between the limits of 26 and 30 tons per square inch, with an elongation of 23 per cent. on a British Standard test length "B."

The sulphur and phosphorus contents should be kept as low as possible, and must not exceed 5 per cent.

Tests for Boiler Rivets

A typical test for boiler rivets is that the shank of the rivet is bent while cold, and hammered until the two parts of the shank touch, without fracture of the outside of the bend (see Fig. 1 (*a*)).

Another test for boiler rivets is that the head whilst hot is flattened until the diameter of the head is 2·5 times the diameter of the shank, without cracking at the edges (see Fig. 1 (*b*)).

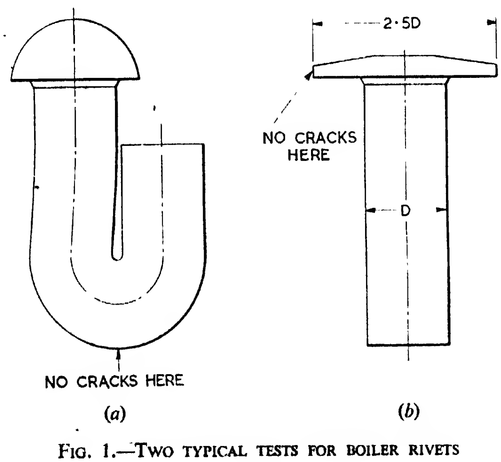


FIG. 1.—TWO TYPICAL TESTS FOR BOILER RIVETS

Procedure for Drilling Holes

All rivet holes should be drilled from the solid plate, if possible after the plates have been bent to shape, and then the plates are taken apart, all rough edges removed from both sides of the plates, so that the edge of each hole is left with a slight countersink.

Rivet Clearance before Closing

Riveting, originally a crudely formed fastening, has become a highly finished mechanical operation, requiring great care in all its details. The rivets when complete should have a sufficient grip in the plates, and should completely fill the holes, which should have no sharp corners.

To attain this condition, the clearance of the rivet in the hole before closing requires careful consideration, and for holes up to 0·8125 in. diameter, the rivet, when cold, would be 0·0312 in. less, and from 0·875 in. to 1·5 in. diameter holes, the rivet shank would be 0·0625 in. less in diameter.

It is important to note that on drawings the diameter of the hole is generally specified, and calculations are based on this practice.

Types of Heads

Rivet heads are of different shapes, according to the particular purpose for which they are required, and Fig. 2 shows the proportions and types of rivet heads in relation to the shank diameter.

For very high-pressure work a special type of rivet is used, as shown in Fig. 3. The rivet, inserted in the hole prior to being closed, is shown in (*a*), and the finished rivet is shown in (*b*). It will be seen that the original head changes in shape from pan head to snap head during the closing operation.

Relation between Rivet Size and Plate Thickness

When deciding upon the diameter of rivets to

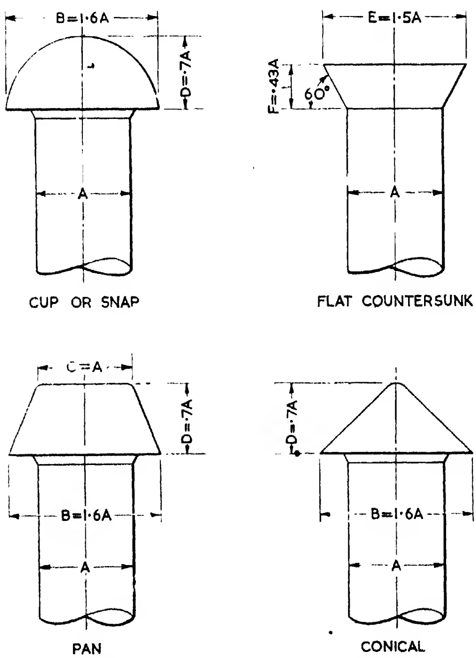


FIG. 2.—DIMENSIONS FOR FOUR GENERAL TYPES OF RIVET HEADS

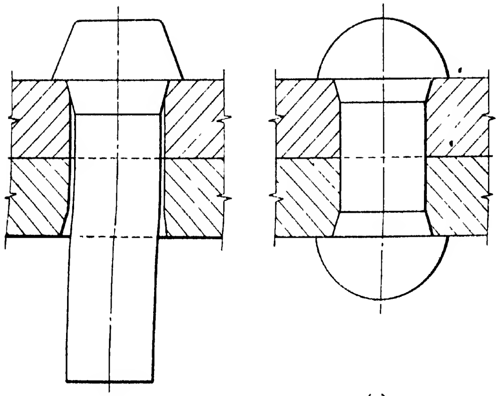


FIG. 3.—SPECIAL TYPE OF RIVET FOR VERY HIGH-PRESSURE WORK

It will be seen that the original pan head changes in shape to a snap head during the closing operation

be used, care must be taken to preserve a correct proportion between the thickness of plates to be joined together, the diameter of the rivet hole, and the length of the shank.

No rivet should be less in diameter than the thickness of the thinnest plate which has to be joined together. The usual formula is $D = 1{\cdot}2 \sqrt{T}$, where T is the thickness of the plate in inches and D is the diameter of the rivet in inches.

Length of Shank to Form Head

The length of the shank required should be just sufficient to form a correct size and shaped head when inserted in the plate junction, and the length of shank to form the head can be obtained from the following formula:

$L = 1{\cdot}5\ D + \frac{1}{8}$, where two plates have to be joined together; and

$L = 1{\cdot}5\ D + \frac{1}{4}$, where three plates are fastened together.

To this length must be added the combined thickness of the plates to be joined.

Example.—If it is required to rivet two plates together, each plate 1 in. thick, then the rivet must not be less than 1 in. diameter. The length of the shank to form the head would therefore be: $1{\cdot}5 \times 1 + \frac{1}{8} = 1{\cdot}625$.

The full length of the shank would then be:

$$1{\cdot}625 + 2 \text{ (combined thickness of plates)} = 3{\cdot}625 \text{ in.}$$

If a rivet is unduly long in relation to its diameter, then no amount of work on the ends will suffice to fill the hole towards the centre part.

Care is necessary in forming rivet heads to ensure that the tools to shape the head are truly concentric, otherwise lipped heads will result. The travelling or outer tool should form the head, while the stationary or inner tool holds the initial head in position.

Heating Temperature

Before the actual riveting takes place, bolts are inserted in every other hole and screwed up tightly. The rivets should be heated to a temperature of not less than 1,700° F., or bright red, but in actual practice this is increased to 2,000° F., or orange colour. The rivets can be heated either in a gas or electric

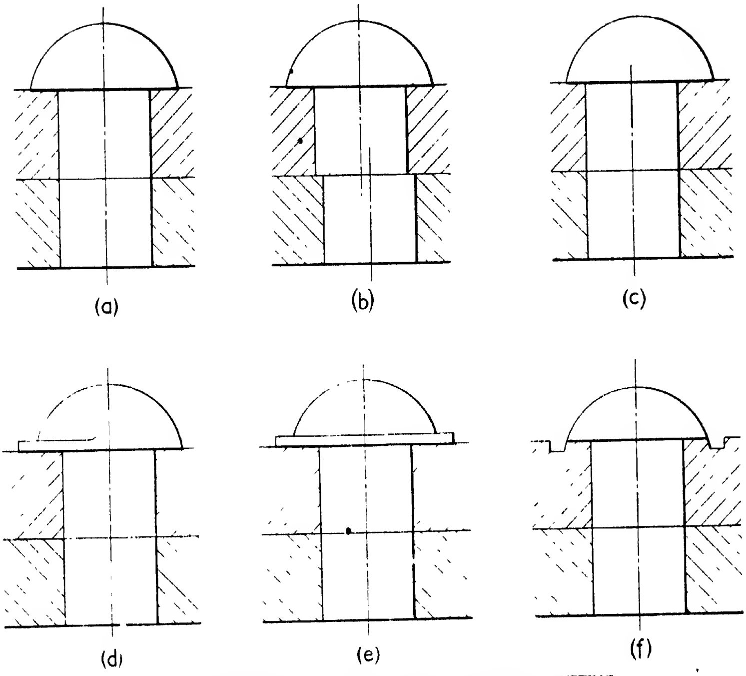


FIG. 4.—EXAMPLES OF CORRECT AND INCORRECT RIVETING
See text for details.

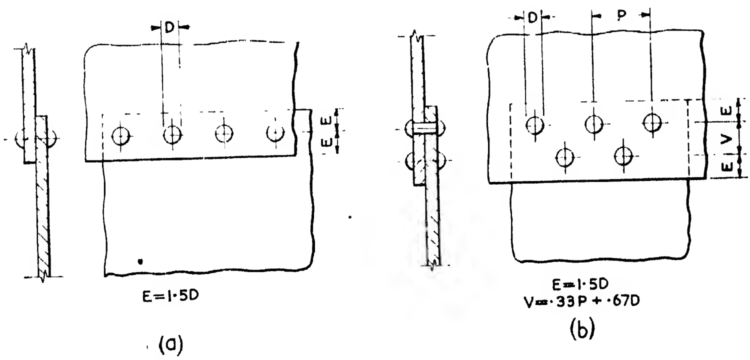
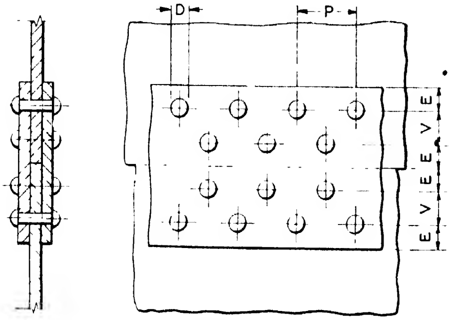


FIG. 5.—RIVETED LAP JOINTS
(*a*) Single lap joint. (*b*) Double lap joint.



E=1·5D
V=·33P+·67D

FIG. 6.—DOUBLE BUTT STRAP JOINT

furnace, or a coke-breeze hearth, care being taken that the heating is uniform throughout and that the rivet is not burnt in any way.

Order of Riveting

A rivet is inserted in the first hole, and the head formed correctly on both sides of the plate, and then another rivet is inserted and formed in the third hole. The bolt in number two hole is then removed and replaced by a rivet. This order of riveting continues until the whole seam is completed.

Closing Pressure

Only sufficient pressure should be used to close the rivets properly, and securely, without indenting, buckling, or otherwise damaging the plate, and the rivets should be allowed to shrink while under pressure from the riveting machine.

Table I gives the maximum closing pressures which have been found satisfactory in practice.

TABLE I

MAXIMUM CLOSING PRESSURES

Diameter of Rivet Hole *in.*	*Maximum Closing Pressure* *tons*
$\frac{11}{16}$	28
$\frac{3}{4}$	33
$\frac{13}{16}$	39
$\frac{7}{8}$	45
$\frac{15}{16}$	52
1	59
$1\frac{1}{16}$	66
$1\frac{1}{8}$	74
$1\frac{3}{16}$	83
$1\frac{1}{4}$	92
$1\frac{5}{16}$	101
$1\frac{3}{8}$	111

Faulty Riveting

Commenting on the examples shown in Fig. 4, (*a*) is good, and should be achieved wherever possible. In (*b*) the rivet holes are out of line, and stress

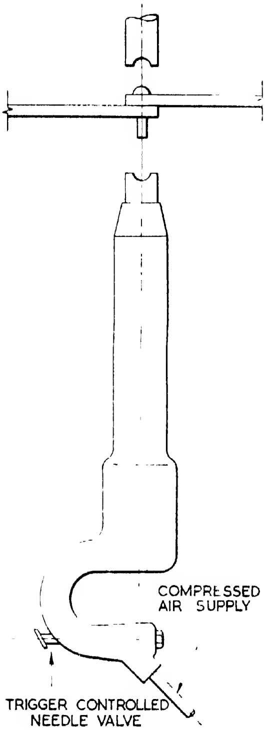


FIG. 7.—PNEUMATIC-TYPE RIVETING MACHINE

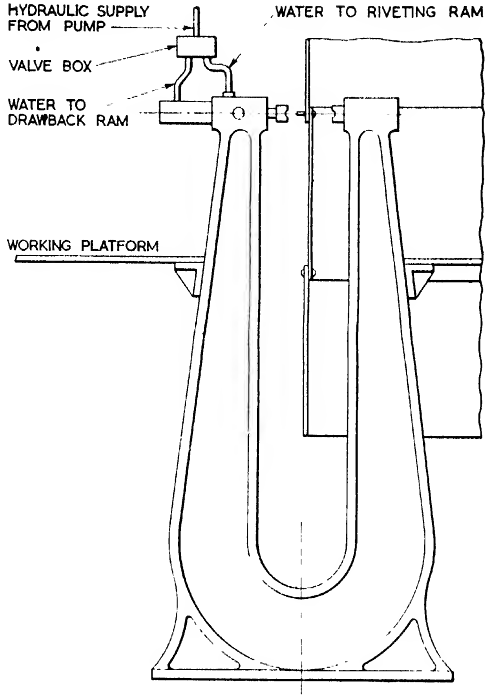


FIG. 8.—VERTICAL-TYPE HYDRAULICALLY OPERATED RIVETING MACHINE

This machine is capable of riveting a joint up to 15 ft. from the outside edge.

concentrations are set up at the sharp corners. This is unsatisfactory, and should be corrected by reamering the holes and using a larger rivet.

The head eccentric on the shank shown in (*c*) may be caused by the tools on the riveting machine not being opposite to each other, or the surfaces of the plate are not at right angles to the machine.

A head which is central on the shank but heavily lipped on one side is shown in (*d*), and is caused by excess of material in the rivet shank. If the lip is not excessive, then this head has no serious defect, but is not considered good practice.

A lip all round the head of the rivet (*e*) may be caused by excessive shank length, or a shallow tool; this type of head is not satisfactory.

A head around which the tool of the riveting machine has indented the

plate as in (*f*) is definitely objectionable. Probably the rivet shank was rather short, or the tool was oversize, or excessive riveting pressure has had to be used to form a head of any description.

Types of Joints

Plates are joined together by means of lap joints or butt joints, and various proportions must be observed to produce a good joint, which will not unduly weaken the plates, or on the other hand will be deficient in rivet strength.

Lap joints are either single or double riveted, as shown in Fig. 5 (*a*) and (*b*), and joints with double butt straps are as shown in Fig. 6, and in each case the various spacings are given.

Hand Riveting

Hand riveting is still in use to-day, usually where machinery or mechanical apparatus cannot be employed, such as steel chimneys, water tanks in country districts, or in confined spaces, such as the interior of a boiler.

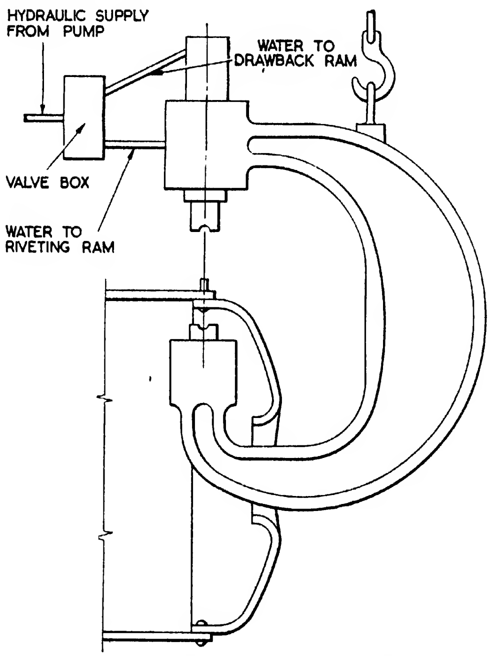


FIG. 9.—HYDRAULICALLY OPERATED RIVETING MACHINE, DESIGNED TO GIVE ACCESSIBILITY IN A RESTRICTED SPACE

Riveting Machines

Riveting machines are of two types, pneumatic and hydraulic.

The principle of a compressed-air riveter (Fig. 7) is that the piston flies rapidly to and fro inside the cylinder barrel and strikes the inner end of the riveting tool. The piston blows vary from 750 to 1,500 per minute, and the riveter has a consumption of from 28 to 35 cub. ft. of free air per minute at 100 lb. per square inch pressure, according to the size of hammer being used.

Hydraulic riveting machines are of many shapes to suit various applications, but the principle is the same in all cases.

Fig. 8 shows a vertical type, which by reason of the long gap between the legs is capable of riveting a joint that is situated up to 15 ft. from an outside edge.

A riveting machine specially designed to give accessibility in a restricted space is shown in Fig. 9.

The hydraulic riveting machine is essentially a small-diameter hydraulic ram, which varies from 6 in. to 9 in. in diameter, and which is fitted with interconnecting mechanism that will enable the ram to be withdrawn after the rivet head has been formed and cooled, all operated by one movement of a lever.

The most modern machines incorporate a timing device, which prevents the ram being withdrawn until the rivet head has cooled sufficiently, to prevent any spring in the plates taking place.

Cold Riveting

So far we have only dealt with fairly large rivets, which can only be driven when hot, but it is possible to close rivets up to $\frac{7}{16}$-in. diameter when cold. Obviously, this size of rivet and smaller ones will only be used on comparatively thin plates, and for $\frac{5}{16}$-in. and $\frac{3}{8}$-in. diameter rivets joining $\frac{1}{8}$-in. and $\frac{3}{16}$-in. thick plates together, a pressure of about 15 tons is necessary to form a snap head of length equal to $1{\cdot}5\ D$.

It has been found unsatisfactory to use $\frac{7}{16}$-in. diameter rivets for $\frac{1}{8}$-in. thick plates, but with $\frac{3}{16}$-in. thick plates very good results are obtained with pressures varying from 16 tons to 18 tons when forming heads equal to $1{\cdot}5\ D$.

H. G.

SHEET-METAL WORK

WITH NOTES ON PLATE-BENDING MACHINES

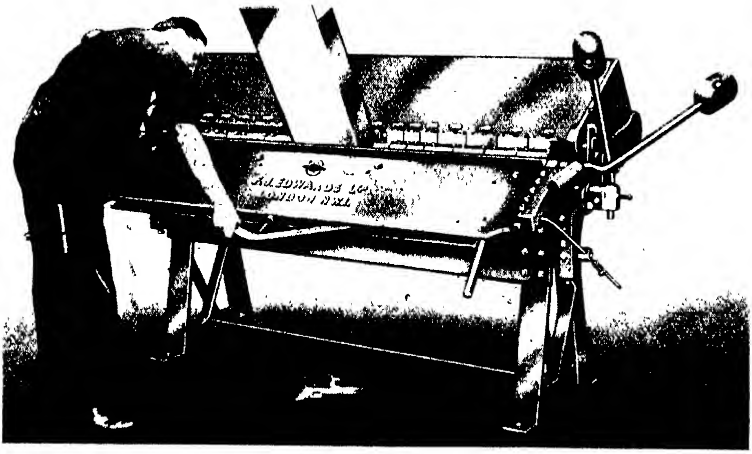


FIG. 1.—PAN OR TRAY FOLDING MACHINE (*F. J. Edwards, Ltd.*)

TYPES OF SHEET METALS

ONE of the cheapest sheet metals is black iron. This is sheet iron rolled to the desired thickness, and annealed by placing in a furnace until red hot, and then allowed to cool down gradually. This process is known as open annealing. By being heated in air, the resultant sheet is covered with scale, owing to the formation of oxide on its surface. To prevent this scale from forming, a process known as "close annealing" is employed, whereby the sheets are packed in a box and sealed from the atmosphere and the products of combustion during the annealing process.

When common black iron is used for outside work, it must be protected from the weather by painting or coating with boiled linseed oil.

Cold-rolled Close-annealed Sheet Iron

A further improvement to the surface of close-annealed sheet iron is to run it through polished cold rolls after annealing. This is known as C.R.C.A. (cold-rolled close-annealed).

Cold-rolled close-annealed sheet iron is used for steel furniture, electric cookers, fires and refrigerators, air-duct and ventilating systems, bins, covers, hoods, chutes, and similar products. It is also an excellent base for paint or enamel.

Silver Finish

The best grade of sheet iron manufactured is known as "Silver Finish." It is used for the highest class of sheet-iron work, but its bright surface needs protecting with paint, enamel, or plating. As it is fairly malleable, ductile, and easy to weld, the smooth, scale-free surface is an excellent ground for the high finish associated with motor-body work.

Blue-planished Steel

Formally known as Russian iron, blue-planished steel has a polished, gun-barrel-blue, oxidised surface, and is used where further surface treatment is unnecessary, e.g. oven interiors. Great care is necessary in handling this metal as, due to the fact that it is supplied covered with grease or oil to prevent damage in transit and storage by rust or scratching, the sheets are liable to slip through the hands and cause injury.

Tinplate

Tinplate is sheet iron coated with tin to protect it against rust. This is used for nearly all soldered work, as it is the easiest metal to join by soldering and, due to tin being the main constituent of tinman's solder, the solder alloys with the tin coating and makes a neat sound joint. Tin is a safe metal to use for culinary purposes, as food is not contaminated by contact. Common tinplates are rolled to the required thickness, annealed, immersed in an acid bath to remove the scale, dipped in flux, and then into a bath of molten tin which adheres to the surface. This first tinning leaves tiny pin holes and, while this is not detrimental for some classes of work. the better qualities receive a second dip in another bath of tin, at a lower temperature, which "floats over" the pin holes left in the first coating. The highest-quality sheets used for culinary and hotel work receive a third dipping in a tin bath, thus ensuring a heavy coating of pure tin on the surface of the iron. Great care is taken to preserve the surface of these sheets, and they are packed in boxes interleaved with tissue paper to prevent scratching in transit. The qualities of tinplates are known as Common, Best, and Best Best respectively.

The sizes and thickness of tinplates are denoted by special marks, not by gauge numbers, and can be very confusing to the uninitiated. It will be noticed that tinplate is only obtainable in fairly small sheets of light gauge. If larger or heavier sheets of tinned iron are required, the material used is known as Manchester plate or "tinned steel," and this may be obtained in all sizes and gauges in which sheet iron is obtainable. Manchester plate is a heavily coated sheet of the highest quality, and is much used for dairy utensils, hotel work, and petrol tanks.

Terne Plate or Lead-coated Iron

Lead would be an excellent metal with which to face iron sheets for protection, except for the fact that lead has little or no affinity for iron, and an addition of tin must be made to get it to "take." In most cases the tin content is low, but for soldered work a terne plate may be used, which is virtually a solder-coated sheet. This is much used for outside work which is to be joined by soldering, such as electric box signs.

Galvanised Iron

Zinc is a metal which withstands contact with water and exposure to weather, but the poor mechanical properties render it unsuitable for many jobs requiring the characteristics of zinc combined with the high mechanical properties of iron. Zinc-coated iron is known as "galvanised iron," but the coating is not electrically deposited, as its name would suggest; the sheet is dipped in molten zinc after being pickled, scoured, and fluxed with sal-ammoniac, the process being the same as used in the manufacture of tinplate. Galvanised tanks and other jobbing work is usually made in C.R.C.A. and galvanised after completion. Thus the zinc seals the joints and coats the edges, which if made of galvanised sheet would be bare iron and liable to rusting.

FIG. 2.—HAND-GEARED BENDING ROLLER

The top roller swings out to enable completed cylinders to be withdrawn without distortion.

(*F. J. Edwards, Ltd.*)

Aluminium

Due to the development of the aircraft and motor industries, aluminium has become the most important and widely used of the non-ferrous metals. Its lightness (specific gravity 2·56) makes it especially useful for aircraft parts liable to very little mechanical strain, the tensile strength being only about 9 tons per square inch. This is very malleable and capable of being worked into most shapes without annealing. The metal "work hardens," and if the job has to undergo much stretching, it is advisable to anneal when the material becomes hard, to prevent the development of splits and cracks. Aluminium is used on aircraft mainly for engine cowlings, fairings, and petrol tanks.

The panels on high-class motor bodies are made from aluminium for several reasons. Firstly, to lighten the body in order to give the high "power to weight" ratio necessary for good performance. Secondly, for ease of working and good surface finish; and thirdly, because, when scoured with a wire brush, a good base is formed for the heavy cellulose coating which is able to hold tenaciously to the scoured surface. As aluminium is rustless it is also durable, and the stripping of paintwork, owing to rust forming underneath, is obviated.

Aluminium cannot be soldered by ordinary methods, as the film of oxide which forms on the metal is tough and tenacious and cannot be broken down with soldering fluxes at ordinary temperatures. Welding and riveting are the methods used to join together aluminium parts (see pp. 84, 355, and 361).

Duralumin

This metal is used almost exclusively for aircraft work, for the fabrication of engine cowlings, fairings, fuselage skin, and tanks, and is a light alloy of high tensile strength (about 18 tons per square inch), and somewhat hard and brittle. For this reason, Dural should be annealed before bending or shaping is undertaken, and, as the metal "age hardens" rapidly, annealing should be carried out at least every two hours, and more frequently if the work entails hammering and stretching, otherwise cracks and splits will appear and the work will be ruined.

Dural cannot be joined by oxy-acetylene welding, and for this reason riveting is the most generally used method for joining parts. It is now possible to join Dural by spot welding with a specially designed electric spot welder capable of producing the heavy current flow combined with the great mechanical pressure which is necessary.

The surface of Dural is very liable to corrosion, and so after the parts are made and normalised, they are subjected to anodic treatment in order to preserve the metal. Dural sheets are sometimes faced with aluminium, thus rendering anodic treatment unnecessary. Aluminium-coated Dural is known as "Alclad" sheet, and the method of working is the same as for Dural.

Copper

The characteristics of copper are its high conductivity of both heat and electricity, its red colour, which is capable of taking a high finish, and its remarkable ductility and malleability. This high conductivity makes the metal especially suitable for hotel and culinary work, but as copper is dangerous when in contact with food, the surface which is liable to contact is coated with pure tin. Articles which are to be plated are frequently made from copper, as this takes a high finish, and is an excellent base for the deposition of plating metals (nickel, chromium, silver, etc.).

Copper can be joined by welding, but a special type of de-oxidised metal must be used.

Brass and Nickel Silver

Brass is an alloy of copper and zinc, possessing good working characteristics, and is used as a base for plated goods. Nickel silver, or German silver,

is an alloy of copper (2 parts), zinc (1 part), nickel (1 part), making a white metal of excellent working characteristics. This is sometimes used in the natural state, as a white metal, but is more generally used for the highest class of silver-plated work.

Zinc

This metal withstands the weather very well, and is used extensively for outside work, such as roof work, gutters, spouts, etc. Care must be exercised when working zinc, as it is short grained (i.e. more granular than fibrous). Zinc is malleable at a temperature just hot enough to be comfortably handled, but is decidedly brittle at low temperatures. Owing to the poor working characteristics, this metal is more generally used as a coating for iron, in the form of galvanised iron.

Stainless Steel

This is an alloy of steel with nickel, chromium, and traces of other metals. In the original form (Staybrite) a fairly high percentage of carbon was present, which made it hard and difficult to work, but at the present time about fifteen grades of stainless steel are manufactured, with characteristics varying between high carbon content (suitable for cutlery and other tools) and a form which is virtually a stainless iron and which is as malleable as mild steel. Some stainless steels are unsuitable for welding, whilst others can be satisfactorily joined by this method (see p. 73).

Electron

This is a light alloy with a high magnesium content, which is coming into prominence for aircraft work. Great care must be exercised in its working and handling, as when in small quantities (filings, turnings, cuttings, etc.) it ignites very easily and burns with a brilliant white flame which can only be extinguished by damping with cast-iron dust, sand, or special extinguishers.

TABLE I.—SPECIFICATION AND COLOUR MARKING OF SHEET METALS USED FOR AIRCRAFT WORK

Specification	*Metal*	*Colour Band*
2.B.16	Brass sheet, half hard, for tanks	Red
3.L.3	Dural sheet	Yellow
2.L.4	Aluminium sheet, hard	Green
2.L.16	Aluminium sheet, half hard	Blue
D.T.D.111	Alclad sheet	Yellow and blue
2.S.3	Mild-steel sheet	Green
3.S.20	Tinned steel for tanks	Black and green
D.T.D.171.A	Stainless steel for welding	Red and black

Air Ministry Specifications

All metal used for aircraft work must conform to an Air Ministry Specification and be tested and inspected before being issued for aircraft work. To make identification easier, the sheets are "Colour Marked," according to the specification, by dabs of paint in the corner of the sheet carrying the inspection stamps.

PATTERN FORMING

Before starting on any project in sheet metal a pattern should be developed to ensure the accuracy of the finished article. The formation of patterns is therefore dealt with first. When a box, cone, pipe, or other shape is being made up, one of the illustrations given will be a guide to procedure. In order to make the worked-out sketches as free from extraneous lines as possible, allowance for joints is not given. To those who are fairly proficient at geometry, the formation of the patterns should prove easy, but full details are given so that the ordinary mechanic, when called upon to make up something for the shop or job, can do so without wading through a lot of figures and formula in an endeavour to carry out the work at hand. To those making up seamless tubes, the patterns can be made from paper or pasted on the tube to provide an accurate line on which to cut the joint line.

Ninety-degree Angle Elbow (Fig. 3)

Nearly all patterns are made up from the development of a 90° angle elbow by full-size drawings of either an elevation or plan sketch. Having made the sketch with accuracy, it is necessary to draw a base line across the sketch as in Fig. 3. The line need not be in the position shown in this example, but immediately under the lower point of the elbow, if so wished. When this is done, make sure the developed pattern will be covered by the space allotted, otherwise it will be necessary to start the pattern drawing all over again. The allowance of margin therefore not only assists in time-saving, but acts in such a manner as to prove to the operator if his parallel lines are correct or not.

With the point of the dividers on the junction of the base line and the centre line, draw a semicircle on the base line equal in diameter to the sketch of the pipe. The semicircle is then divided into six parts without altering the dividers by using points 0, 3, and 6 as centres. Mark the sections off as shown in Fig. 3. It will be seen that this semicircle represents half the circumference of the actual pipe when finished. As both views of the pipe are the same, it is not necessary to portray the side of the pipe not seen in the illustration, nor is it necessary to outline the other pipe, as the pattern will be exactly the same. The figured points 0–6 will represent six equal spaces around half the circumference of the finished pipe, there being no necessity to draw the other half, as the outline is the same. On the other hand, it will be necessary to mark out the unseen side of the pipe; therefore, as one side of the pipe is the same as the other, the figures can be repeated. On the sketch of the pipe elevation, then, draw lines from the semicircle sections to the joint line at the elbow, and where these lines meet the joint,

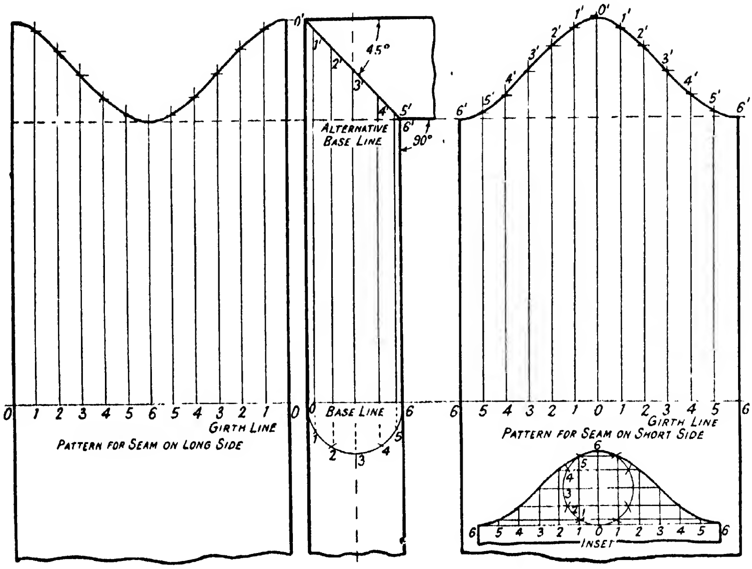


FIG. 3.—PATTERN FOR 90° ANGLE ELBOW

they will mark the places on the developed pattern where the sheet of metal will have to be cut to shape. As the sections on the semicircle equal twelve spaces around the actual pipe, it will be necessary to draw twelve parallel lines on the pattern, the distance between them being equal to any one of the sections on the semicircle, and *not the base line*. In this instance the base line is there to enable the operator to measure distances from the base line itself to the joint line. In the illustration two patterns have been given showing the difference in the patterns when the seam of the pipe is on different sides. At right angles to the parallel lines the base line is drawn and numbered as shown. Set the dividers to the distance 0 to 0′ (base line to top of joint line), and with one point of the dividers on the mark 0 on the girth line of the pattern scribe the length 0′ on the pattern itself. Scribe out lengths with the other numbers.

The illustration shows the scribings that will be made on the sheet, and now it will only be necessary to freely connect up the marked points to form the correct shape of the joint.

No allowance has been made for jointing, therefore the difference will have to be drawn in before the sheet is cut. In the case of welding there will be no necessity to add anything to the pattern in any way.

It is assumed that both pipes will have the seams on the short side; therefore the patterns will be the same. This is not absolutely necessary, and the practised operator can draw both layouts on the same sheet, but in this instance the

patterns are shown separately to enable the reader to understand the method with greater ease.

Another Method

There is another simple method for marking out a 90° elbow, but it applies *only to a right-angled elbow*. The first method has been given to show the principle on which all cylindrical sheets are marked out, whereas the inset in Fig. 3 pertains to no other layout. A circle equal in diameter to the pipe is divided into twelve equal parts, the girth line 6–6 being divided up in a like manner. The points to form the curve are obtained by running the construction lines up and across as shown in the inset.

Ninety-degree T with both Pipes the Same Diameter (Fig. 4)

This is a fairly straightforward job, but although it looks a little more complicated (Fig. 4) it is carried out by the use of only half the number of figures on the semicircle as the previous layout. The reason is that only a quarter of our circle is needed to produce the correct profile of the joint on the down pipe. One-quarter of the circle is divided into three equal parts without altering the legs of the dividers which were set to the radius of the pipe. In this instance 0 starts from the centre line, as this is the most suitable line for the seam, and twelve spaces marked off equal to 0–1, or 1–2, or 2–3, all being equal in dimensions. Lines at right angles are run up from the twelve places, and along them are measured the distances from the base line to the outline of the pipe from which our pipe branches. It will be noted that all lines from the base line bearing the same number are the same length.

Forming the Hole

On the flat sheet that will eventually form the joining pipe draw a line 3–3. This line is the girth line on the pipe, and *not a centre line*. Along this line space out 0–1, 1–2, and 2–3, all equal and obtained from the distance apart of these numbers on the circle. Set the dividers to 0–6 on the elevation and mark off 0–6 on both sides of a line drawn at right angles through 0 on the girth line. Similar lines having been drawn from 1 and 2 respectively, they also are marked off 1–5 and 2–4 each side of the girth line, thus giving the correct shape of the hole that will have to be cut in the sheet before it is rolled into a pipe. The hole has been set above the branch pipe pattern so that the reader can, graphically, obtain some idea as to how the actual hole shape is formed.

Ninety-degree T running into Larger Pipe (Fig. 5)

The patterns in this instance (Fig. 5) are different from the previous T-piece, in that the larger diameter of the main pipe flattens out the developed curve on the smaller branch pipe. The spacing on the girth line of the larger pipe is also produced in a different manner, owing to the sections marked off on the semicircle imposed upon the base line of the smaller pipe being smaller than similar sections would produce if the larger pipe was similarly treated.

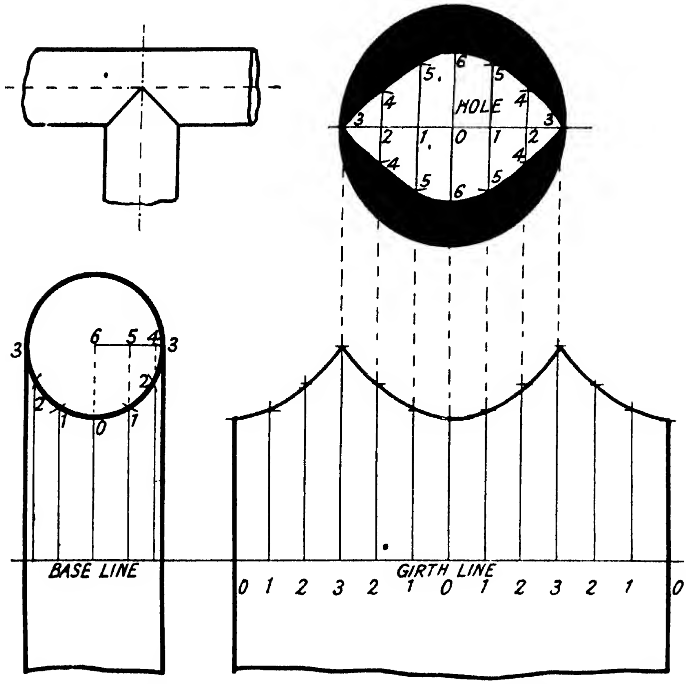


FIG. 4.—PATTERN FOR T-PIECE WITH BOTH PIPES THE SAME DIAMETER

In this instance the spacing on the girth line *EFGHGFE* is set out with *H* in the centre and spaced *H* to *G*, *G* to *F*, and *F* to *E* on either side of *H* on the circle denoting the larger pipe. The *lengths* of these lines will be marked from the base line to the periphery of the base circle of the smaller pipe, viz. *D* to *L* on *H*, *C* to *K* on *G*, *B* to *J* on *F*, and the point *E* will be on the same spot as *A* on the girth line.

Letters have been used to denote the various spots, as figures rising above the value of 10 would be somewhat confusing, but it must be remembered that the practised mechanic seldom uses any characters to denote the various points, carrying the names or figures and letters of the points in his memory. In any description it is necessary to use some form of figures and lettering as an explanation of the method of procedure.

The marking out of the down pipe is on the same principle as the preceding examples and is *L* to *H* on lines *D*, *K* to *G* on lines *C*, *J* to *F* on lines *B*, and *A* to *E* on lines *A*. In the example shown the seam is at *A*, but it can be arranged at *D*, if thought necessary, by fixing *A* at the point now allotted to *D* and sketching out the pattern accordingly.

Thirty-degree Branch Pipe, both Pipes the Same Size (Fig. 6)

The principle of marking out the patterns remains the same, although there is a slight variation (Fig. 6). On both patterns all figures have been left out on the cutting lines, but dotted lines showing how the various points are produced have been drawn in. It will be noted, however, that only a quarter segment of the semicircle formed on the base line of the vertical pipe has been used to obtain the points for cutting out the hole, although the semicircle itself has been figured

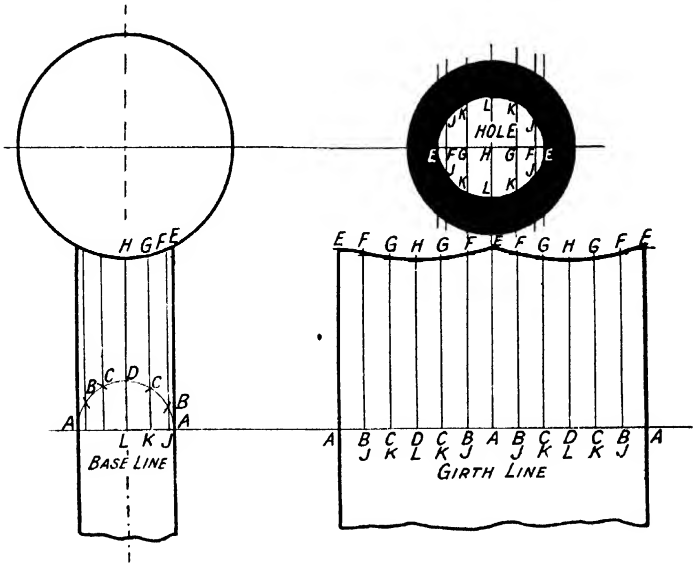


FIG. 5.—PATTERN FOR T-PIECE WITH PIPES OF DIFFERENT DIAMETERS

to show the circumference of the pipe and the position of the hole. The joint between the two pipes has been drawn in, although the position was not known until the parallel lines drawn on each pipe met and denoted where the joint should be. On the branch pipe it will be noted that line 1 on the pipe elevation intersects line 1 on the pattern of the same pipe; exactly the same takes place with other figures of the same denomination.

Regarding the figuring on the other pattern, it will be noted that 0 intersects 0 on the pattern, 1 intersects 1, 2 intersects 2, 3 intersects 3, 4 intersects line 2 on the pattern again, 5 again intersects 1, and 6 again intersects 0, thus producing the correct-shaped hole in the vertical pipe.

Right-angled Small Offset T (Fig. 7)

The pattern of the small pipe (Fig. 7) is laid out by dividing into twelve equal parts measured on the semicircle built upon the base line of the smaller

pipe. Marked off at lengths 0–0, 1–*A*, 2–*B*, 3–*C*, 4–*D*, 5–*E*, and 6–*F* from the small-pipe base line and *not from the sections on the semicircle*, the small-pipe pattern shape, where it meets the large pipe, is illustrated with its peculiar form specially on the line 6. This is owing to the smaller pipe being just a little larger than half the diameter of the large pipe. The figure has been specially produced to give an idea of the shape, although not likely in actual practice. The girth line of the large pipe is laid out, and at distances along it are scribed off measure-

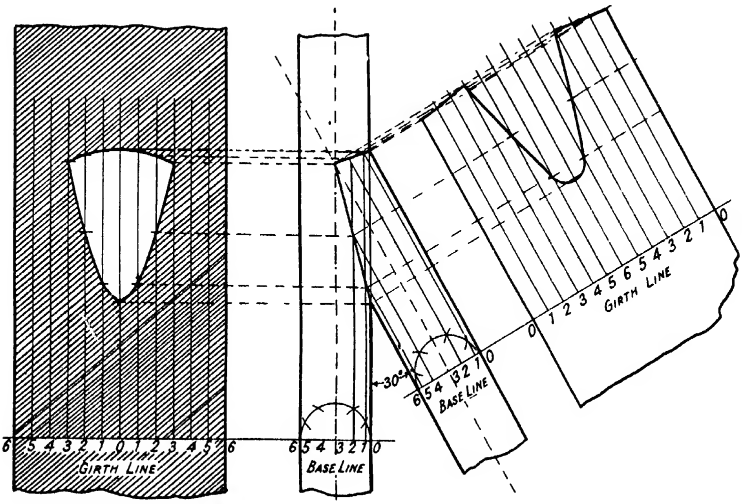


FIG. 6.—PATTERN FOR 30° BRANCH PIPE, BOTH PIPES BEING THE SAME SIZE

ments 0–*A*, *A*–*B*, *B*–*C*, *D*–*E*, and *E*–*F*, obtained from the circle denoting the larger pipe. Lines at right angles are drawn through these points and their length determined from the small pipe base line to 1, base line to 2, base line to 3, and so on. As 1 is the other end of *A*, the dividers' point is placed at *A* on the girth line and the point 1 marked off on either side. The cutting line of the hole is freely drawn in.

Forty-five Degree Small to Larger Offset Pipe (Fig. 8)

This layout (Fig. 8) is a little more complicated than those already explained. In this instance the small pipe has the usual base line and its imposed semicircle, but it has been found necessary to number both sides of the semicircle, as the obverse side of the branch pipe takes up another shape to that shown on the front. It has also been necessary to produce a similar base on the top of the large pipe. In perspective this semicircle would be at right angles to the lower semicircle and has been drawn to locate the position of the joint on the large

pipe. From the point of view of the lines drawn along the small pipe, the position of the lines remain constant, but those on the other side are of different lengths. Observation of the sketch will show that the lines drawn through 0, 1, 2, 3, 4, 5, and 6 meet the same numbered lines drawn from the base at the top of the large pipe. Where these lines intersect will be the joint line on the seen side of the pipe, but where lines 7, 8, 9, 10, and 11 intersect the similarly numbered lines (dotted for ease in viewing) on the large pipe will be formed the joint on the unseen side. The unseen joint line is also dotted. The circle equal in diameter to the large pipe has been drawn to locate the small base pipe lines in their correct position. The pattern of the small pipe is numbered from 0 to 11 and again 0 (0 being the same spot as the 0 on the other side of the drawn pattern). Lines drawn at right angles to the side of the small pipe will intersect the vertical

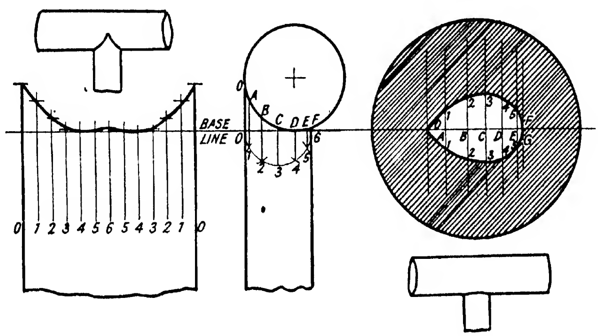


FIG. 7.—PATTERN FOR RIGHT-ANGLED SMALL OFFSET T

(and parallel) lines drawn upwards from the small-pipe base and spaced equal to the sections of the semicircle. Number 0, where the two pipes meet, will intersect lines 0–0 on the pattern, also where lines 3 intersect on the elevation is the point from which a line will be drawn to line 3 on the small-pipe pattern, and so on from all the other intersections.

The shape of the hole is obtained by constructing the line *A–B* from the point *A* at right angles to the large pipe. At right angles to the line *A–B* draw the line 0. Measure off 0–1 on the large pipe circle and space 0–1 on the line *A–B*. Then 1–2 and 2–3. On the other side of line 0 mark off 0–1, 11–10, and 10–9, not forgetting that these measurements are obtained from the large circle where the extended lines from the base semicircle are imposed on it.

There is nothing mysterious in the short straight lines from the top base line to the periphery of the large circle. The position selected for this base line is the most suitable, and the straight lines simply convey the true value of the measurements set out on the semicircle. The same arrangement is met with from time to time in such work.

The other measurements pertaining to the hole should need no explanation,

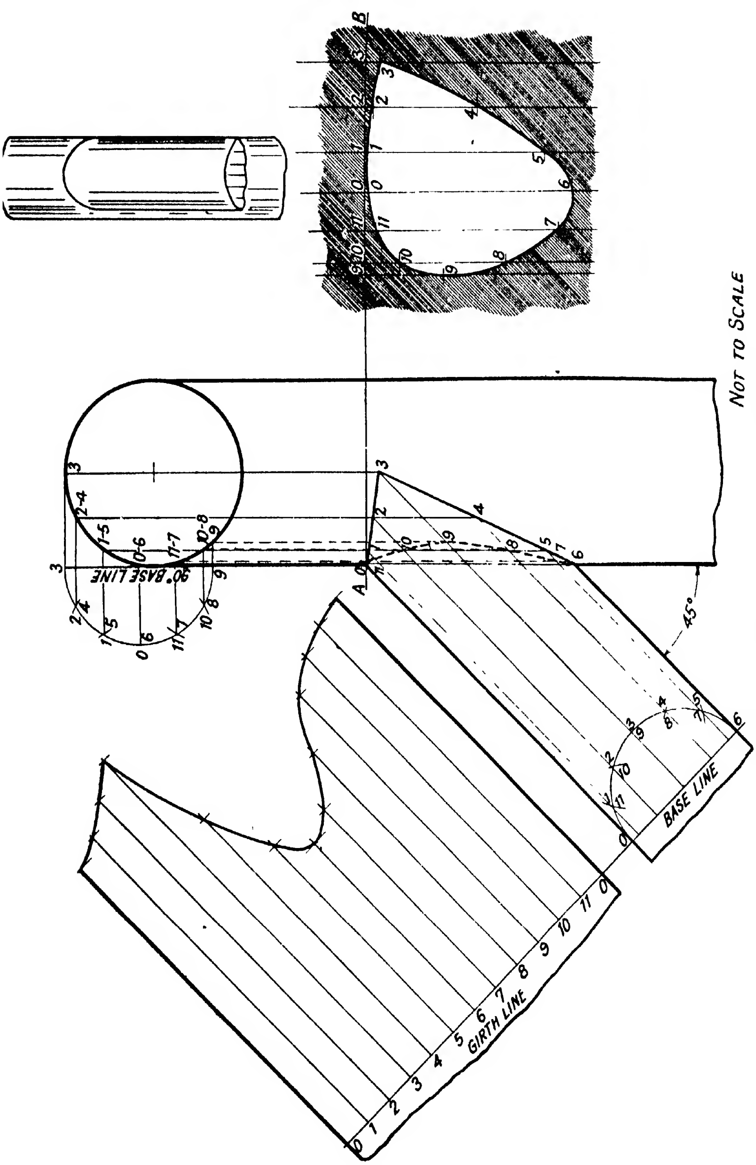


FIG. 8.—PATTERN FOR 45° SMALL TO LARGER OFFSET PIPE

excepting that the markings are parallel continuations of the various intersecting points on the elevation.

Forty-five Degree Small to Large Pipe on Centre Line (Fig. 9)

In view of the fact that a more difficult branch has been described in the last section, it is not necessary to go into many details with this form of joint (Fig. 9). The base line on the branch is numbered as usual and the semicircle sections spaced along the girth line of the pipe itself. From the quarter circle imposed on the large pipe, numbered on both sides, it can be seen that both the sides on the elevation are alike, therefore there is no necessity to increase the number of points. The actual joint line has been left out for a better view of the intersections and the conveyance of the cross-lines to the layout for the hole in the other pipe.

Mention of the fact that the pipe circumference is the diameter $\times$ 3·1416 should warn the operator that patterns should be checked against a rule before any cutting is carried out. The slightest error on sectioning the semicircles will be multiplied by twelve in the layout of the pattern. The difference in method of laying out the 90° base line to that shown in Fig. 8 has been done purposely to show the alternative when it suits the case. A little study of the situation will prove there is no difference whatever as to the result.

Pipe Bends (Fig. 10)

It is impossible to draw the actual pipe bend until one has laid out certain measurements of both the length and the offset of the bend itself. Fig. 10 shows the bend, but it has been produced from the layout of the inset in the left-hand corner.

Let the parallel lines *A* and *B* form the beginning and the finish of the desired bend, and the lines *C* and *D*, both at right angles to *A* and *B*, form the centre lines of the traight pipes, therefore the offset of the bend. The lines *A*, *B*, *C*, and *D* form a rectangle; therefore from the corners in the same direction as the bend draw the line *G*. The line *G* is then divided into four equal parts as shown in inset. It is easily carried out with the dividers by creating the point *G* first. From point *G* and the corner in direct line the dividers should be set to a little over the half-way mark and so provide a guide to lay out the lines *X–E* and *X–F*, which are at right angles to the line *G*. By using the dividers as stated there is no necessity to use a set-square. Carry on the lines *X–E* and *X–F* until they intersect respectively the lines *B* and *A*.

The points *E* and *F* will be found to form the true centres of the bend. The bend should now be formed into an equal number of sections (eight in this instance). A centre line should be drawn through one of the equal sections, and upon this should be built up the usual semi-circle showing half the circumference of the section. The semicircle is divided into six equal parts and numbered 0, 1, 2, 3, 4, 5, and 6. Vertical lines from the centre line are drawn to meet the numbered points on the semicircle. With one point of the dividers on point *F* they are set to the verticals on the centre line and radii produced to meet the

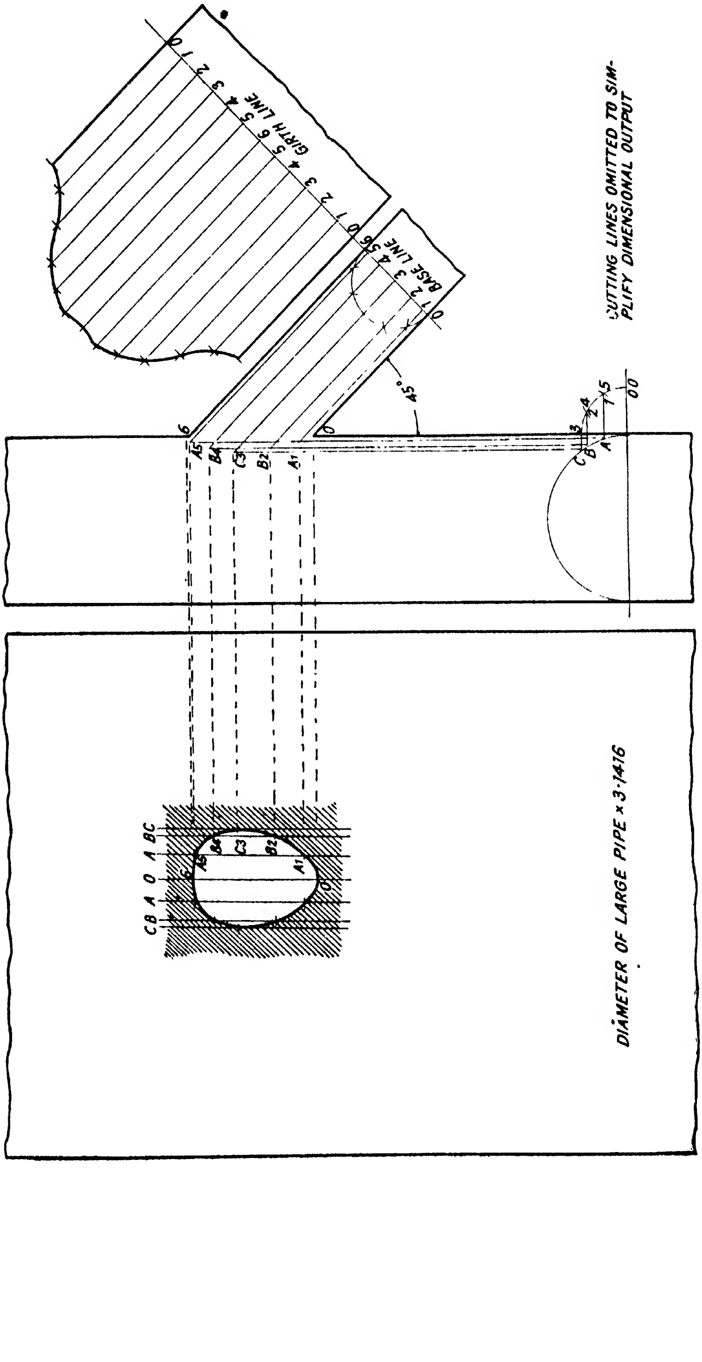


FIG. 9.—PATTERN FOR 45° SMALL TO LARGE PIPE JOINT ON CENTRE LINE OF LARGE PIPE

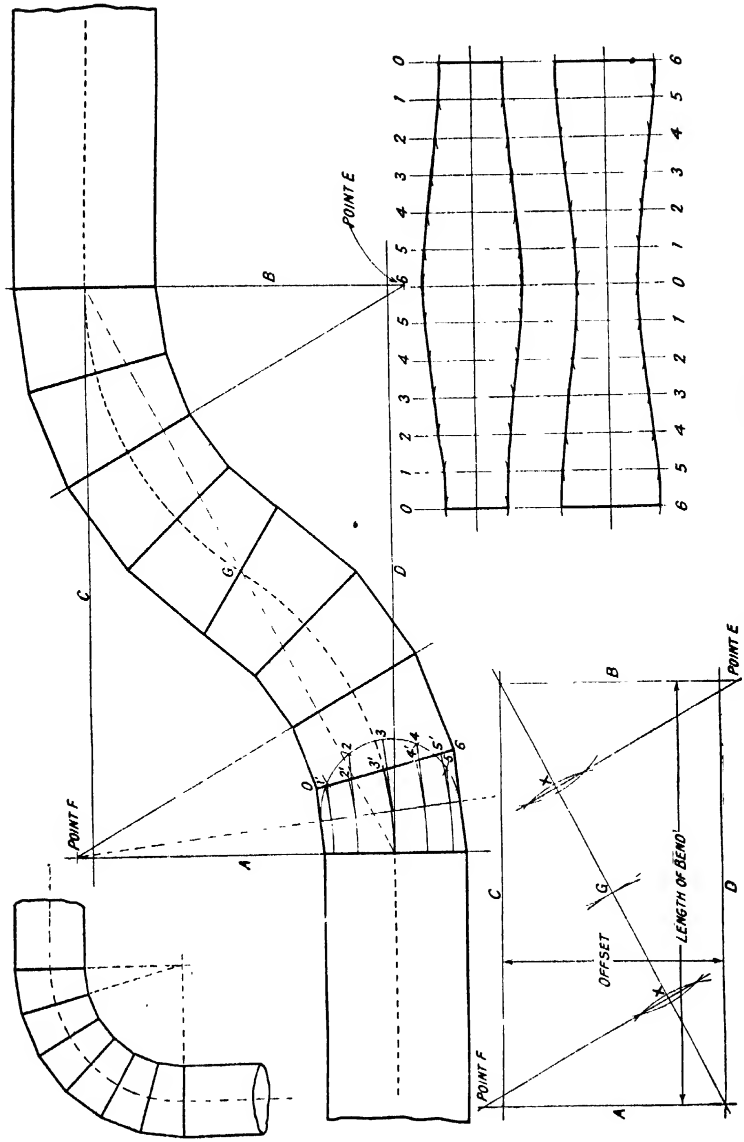


FIG. 10.—PATTERN FOR PIPE BEND IN SEGMENTS

joint line of the section; 0 and 6 remain constant, but the radial lines are numbered 1′, 2′, 3′, 4′, and 5′ respectively. The patterns are laid out in the ordinary manner in twelve parts equally spaced from the sections on the circumference of the semicircle and *not the centre line which has formed the base line*. From the point of uniformity the seam should remain on the same side, therefore two patterns are shown needing sections of four each to be made up.

From this same layout it must not be thought that a right-angled bend can be produced owing to the lines *A–B* and *C–D* not being equidistant. A right-angled bend is shown in the inset of Fig. 10. The bend can have any number of sections, providing they are all equal in size; therefore there is no necessity for the joint line of a section to come on the 45° line of the layout. In the inset the number of sections happens to be six, but the number could be five or seven, according to material and size of the pipe, and this applies to all bends.

Cones (Fig. 11)

Plain cones, if small, are easily developed by sketching out a half-elevation and graphically working out the pattern, but this is not always possible; therefore the formula is herewith given and illustrated in Fig. 11. Invariably the diameter of the base and the height are known, but if any two sides are at hand, the length of the third side can be obtained by arithmetic. The formula is based on the solution of right-angled triangles, and, as half the elevation of a cone is bound to form a right-angled triangle, the formula given in Fig. 11 is of service. This formula does not apply to triangles without one of the angles being 90°. In our illustration the "slant length" is side *A*, the height of the cone side *B*, and half the base line forms side *C*. Our cone has a height of 10 in. (*B*) and half the base diameter is 15 in. (*C*); therefore the sum resolves itself into $\sqrt{(10^2 + 15^2)}$ and equals $\sqrt{(100 + 225)}$ and results in the slant length being 18·0278 in.

In arriving at the amount of the gap to be cut out of the pattern, it is sometimes advisable to calculate the sum of the gap itself instead of the length of arc. If that is so, the following is the formula:

$$(\text{Slant length} \times 2) - (\text{Half the base diameter} \times 2) \times 3{\cdot}1416.$$

This equals

$$(18{\cdot}0278 \times 2) - (15 \times 2) \times 3{\cdot}1416 = (36{\cdot}0556 - 30) \times 3{\cdot}1416 = 19{\cdot}02427$$

(approximately $19\frac{1}{32}$ in.) to be discarded from the pattern.

Another method in degrees:

$$\frac{360^\circ \times \text{half base length}}{\text{Slant length}} = \frac{360 \times 15}{18{\cdot}0278} = 299{\cdot}5^\circ$$

length of arc, or 60·5° the length of gap to be cut from the arc. Graphically the length of radius of the arc is obtained by placing one point on the centre line where the slant length touches and opening the dividers to the length of slant and constructing a circle. On the complete base line of 30 in. a semicircle is drawn and a half of this is again divided into three. Twelve of the sections are then spaced off around the circle on the pattern and should produce the point from

where a line is drawn to the centre of the circle of the pattern and form the section to be cut away from the pattern.

All measurements should be checked with a steel tape or piece of wire.

Conical Elbow on Parallel Pipe (Fig. 12)

In this example of sheet-metal work (Fig. 12) we have added another rule to those in the preceding pages. The new procedure is to draw the elevation of the vertical pipe and construct at the end a circle of the same diameter as the pipe. This is absolutely necessary, as the lines forming the side of the cone must touch the circle in the same manner as the parallel lines of the pipe. Unless this is arranged, the cone, where cut to form the joint, will be a different dimensioned ellipse to the ellipse formed on the parallel pipe where it is cut to form the joint.

An inset to Fig. 12 shows an incorrect layout where the dotted circle only touches one pipe instead of both. It will be noticed that the cone pipe is produced right through to the outer edge of the vertical pipe, not only to prove that it touches the circle as already explained, but to show the true value of the cone base. Upon this base is produced the usual sectioned semicircle with its lines drawn at right angles to the cone base. From this line it will be noticed that the lines are then drawn to meet at the apex of the cone, but where they reach the joint line (the position of which we knew when the elevation was drawn) they are then deflected parallel to the base line until they reach the surface of the cone. From these points lines are drawn with the apex of the cone as a centre, whilst the intersecting lines are, as usual, spaced from the sections on the cone-base semicircle.

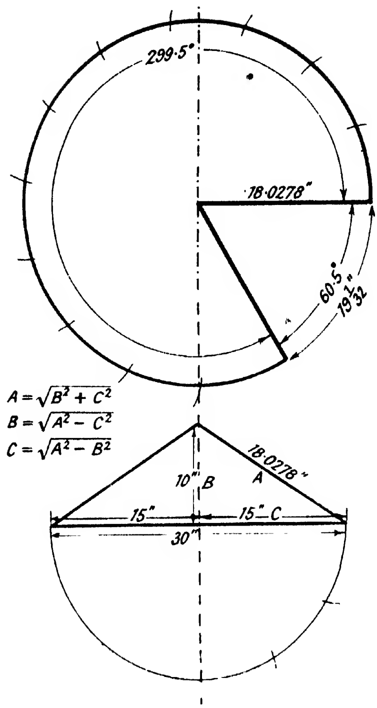


FIG. 11.—PATTERN AND FORMULÆ FOR CONE

Be sure this spacing is marked off on the line 0, otherwise the dimensions of the divisions will not be the correct size. It will be seen that the angle is marked (?°). This has been done so that the angle should not be taken for granted as a right angle, although very near it. It should also be observed that, owing to the cone, the joint line does not pass through the centre of the dotted

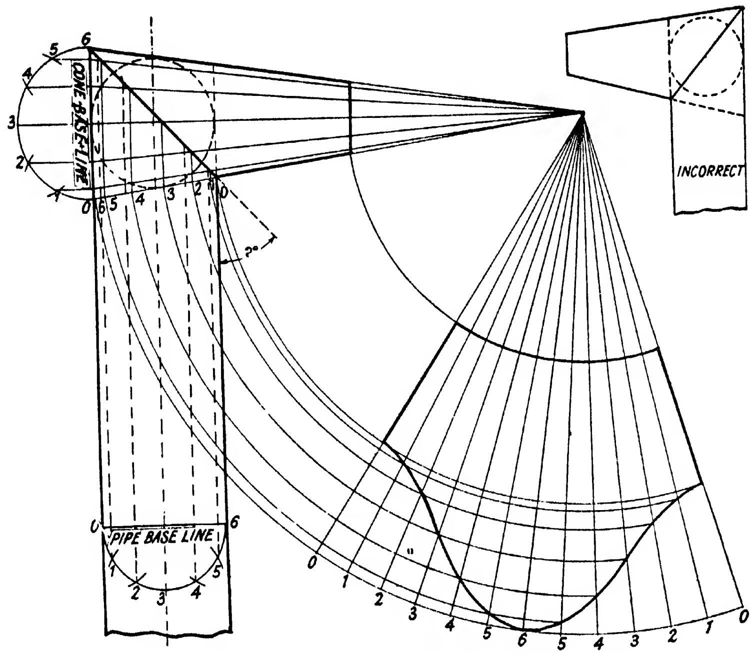


FIG. 12.—PATTERN FOR CONICAL ELBOW ON PARALLEL PIPE

circle, which it would do had the elbow been one of parallel pipes of equal diameters.

It is wise in all sheet-metal work to take nothing for granted, and this is an excellent example. The parallel pipe has a base line of its own and the lines drawn along the pipe are another proof that the lines differ for each pipe. The pattern of the parallel pipe is not shown, as examples of the development of the pattern have already been given.

Cone, Angled Top and Bottom (Fig. 16)

Fig. 16 looks somewhat complicated, but is really straightforward, whatever the angle of either cone or angles at the ends. The bottom of the cone elevation is extended until a base line at right angles to the centre line can be drawn and sectioned on the semicircle, as in other instances. From the base line 1, 2, 3, 4, 5, and the outside, lines are conveyed to the apex of the cone. On the edges the lines are diverted to the outside of the cone so that their true value can be conveyed by radial lines to the pattern. The radiating lines of the pattern, drawn from the cone apex, are equally spaced as the sections on the semicircle and

FIG. 13.—CUTTING SHEET METAL (1)
Marking out the hole to be cut.

not the base line. The spaces are marked out on the radial line 0, otherwise their value will be incorrect. At the small-angled end of the cone, lines are again drawn parallel to the base line until they reach the side of the cone elevation, and from there, using the cone apex as a centre (*X*), they mark off the radiating lines at points of the same number, exactly as the ones at the other end of the cone. The larger end of the cone has been chosen on which to form the base line, on account of its larger size and the lesser possibility of error in consequence; otherwise it makes no difference as to which end the base line is formed.

Large Cone with Two Others imposed at Different Angles (Fig. 17)

Fig. 17 is an example of cone joints specially set out to explain the system, although not likely to happen in actual practice. However, it may be the lot of the operator to be called upon to make up something based upon the method of making such patterns, especially as the principles explained are used in everyday practice.

It will be noted that in laying out the design the dotted circle has had to be used before the imposed cones can be drawn in, also the joint lines are not

FIG. 14.—CUTTING SHEET METAL (2)
Making hole to start pneumatic hand cutter (see Fig. 15).

known until the detailed sketch has been produced. Those parts of the cones not actually in the finished article have been dotted in so that it will be known where the joints will be located.

Having drawn in the three cones, run a pencil line from *A* to *C*, then another line from *B* to *D*, and from the point where these two lines intersect run a line to *E*. Thus will be formed the joints of the three cones. The unwanted parts of the lines *A–C* and *B–D* should be rubbed out to save confusion, as they may be mistaken for wanted lines.

The usual semicircle has been drawn on the base of the vertical cone, but

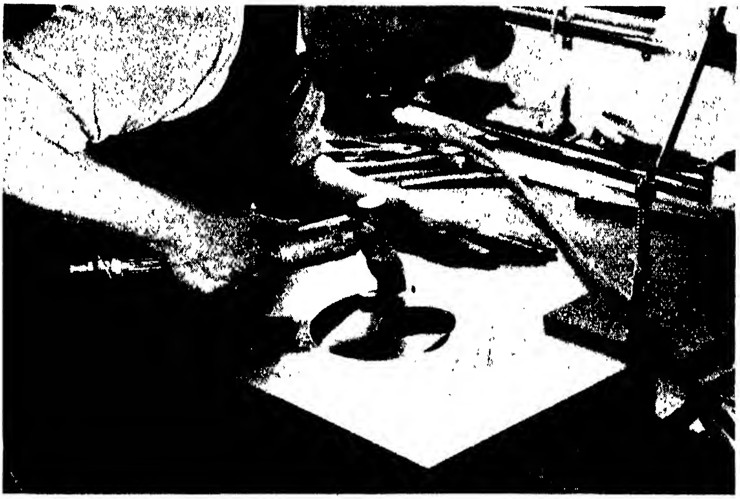


FIG. 15.—CUTTING SHEET METAL (3)
Cutting hole in $\frac{1}{16}$-in. sheet-metal plate with pneumatic power shears
(*Tecalemit, Ltd.*)

with the two other cones the semicircles have been drawn on the smaller ends. This has been done so that the layout can be clearly seen. It may be thought that it is a change of principle to place the cone base semicircle on the other side of the cone base, but the inset shows that the result is the same. The right-angled lines drawn *from the sections* of the whole circle meet on the base line from whichever side they be drawn. For explanatory reasons the same apex points have been used for both the elevation and the respective patterns, although the radial connecting lines have been left out on account of the inability of sorting out the many lines in such a small space.

The reader should test out the elevations and their relationship with the patterns with dividers, when the layout will become clear.

It will be seen that on two of the elevations and patterns there are lines

marked *X*. The reason these are in evidence is that neither of the lines 0–6 meet some of the essential points on the joint. On the vertical cone line 3 does not touch the highest point of the joint, and it is imperative that this point should be known; therefore the extra line from this point to the base line is shown by laying a straightedge from point *X′* to the specially required point on the joint line, drawing in the necessary line to the cone base line. From here it runs at right angles to the periphery of the semicircle, thus giving its true position on the pattern. It is there spaced off from 3 towards 4 and marked with an *X*. The points can be clearly seen on the pattern in their correct positions. It has been found necessary to use these special lines in all three cones.

It is good exercise for the mechanic to lay out such formations, not forgetting to base the designs on the use of the dotted circle, notwithstanding the fact that the centre of the circle is frequently well away from the joint common centre.

Conical Hopper imposed on Slant Pipe (Fig. 18)

Fig. 18 shows that we have arrived at a further stage in the development of both pattern and shape of the hole to be cut in the slant pipe.

The usual semicircle showing half the circumference of the top of the hopper is drawn on the elevation and section, and then numbered. A base line semicircle is drawn at a suitable position on the slant pipe (it does not matter exactly where), but *not sectioned* off. The base line, which is, of course, at right angles to the slant pipe, is extended and marked *A–B* for reference. Lines are extended from the base line of the hopper, all joining at the apex of the hopper cone. Dotted lines are then drawn parallel to the slant

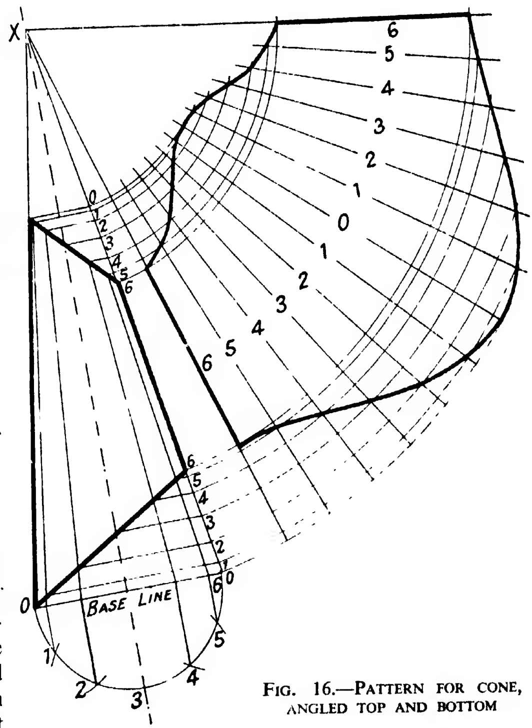


Fig. 16.—Pattern for cone, angled top and bottom

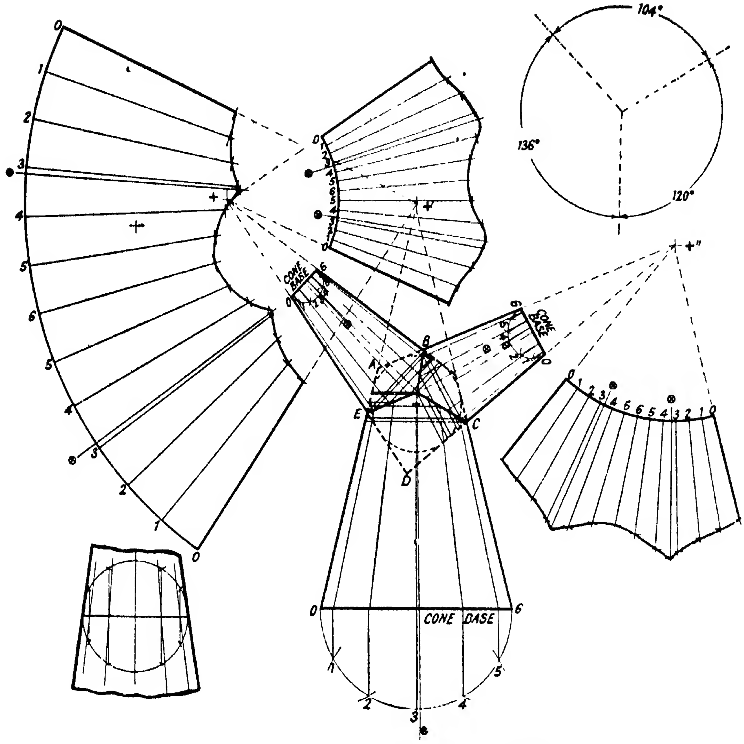


FIG. 17.—PATTERN FOR LARGE CONE WITH TWO OTHERS IMPOSED AT DIFFERENT ANGLES

pipe and pass right through the line *A–B*. The length of the dotted lines on the outer side of the line *A–B* are determined by measuring the distance along the lines reaching from the periphery of the semicircle to the base line on the hopper. Thus the line 1–1, 2–2, 3–3, 4–4, and 5–5 are transferred to the dotted 1–1, 2–2, and so on.

We now draw the line *C–D* through the apex point *E*. This line is parallel to the slant pipe and passes through the line *A–B* at right angles. Where *A–B* and *C–D* intersect, mark the point *F*. From the point *F* draw dotted lines to the extended dotted lines and join them where they have already been distanced off from the line *A–B*. The lines radiating from the point *F* will then pass through the semicircle drawn on the slant-pipe base line. At the points where they intersect the semicircle draw lines parallel to the slant pipe until they reach the lines drawn on the hopper of similar numbers. The points of intersection will form the joint between hopper and slant pipe.

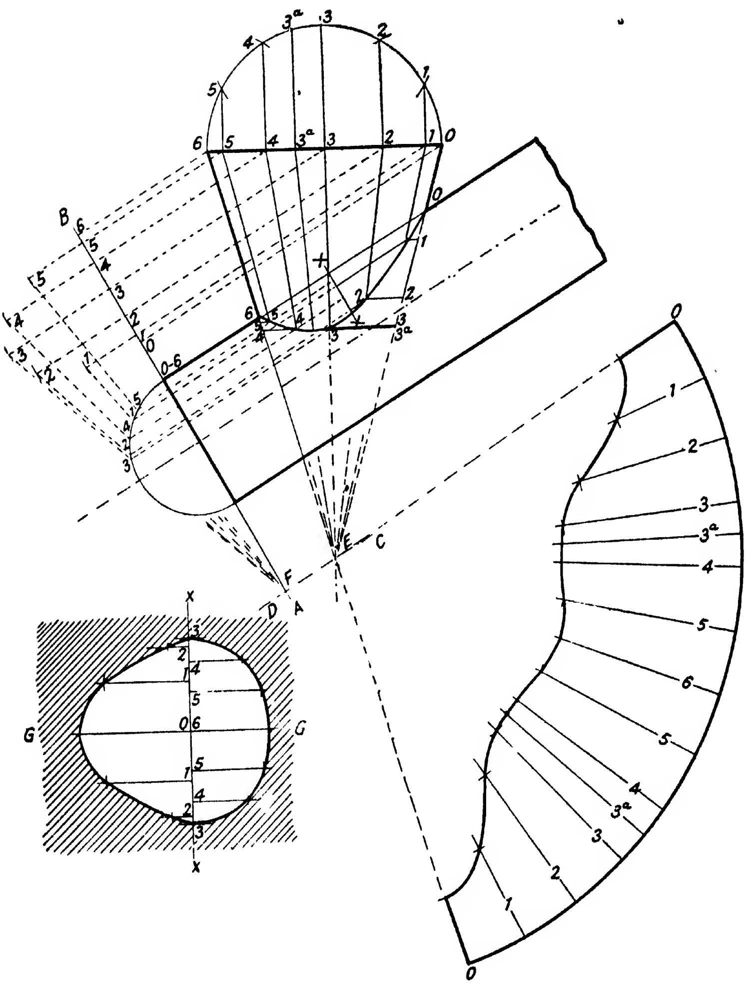


FIG. 18.—PATTERN FOR CONICAL HOPPER IMPOSED ON SLANT PIPE

FIG. 19.—A MODERN SHEET-METAL PRODUCT
Fixing an air fan to its sheet-metal case.

Draw in the joint line, and then, parallel to the hopper base line, draw in from the intersections the lines leading to the extended edge of the hopper elevation. The usual twelve lines radiating from E will represent the circumference of the hopper, the spacing being *equal to the sections on the hopper semicircle*, and spaced out on radius 0, which will form the top edge of the hopper itself. The actual lines drawn by using E as a centre have been left out owing to the number of lines already in use. The line X–X will be noticed drawn at right angles to the slant pipe and starting from the centre line (3) where it meets the slant pipe. It is on this line the details of the hole will be laid out.

From this line the dotted lines 1 and 2 have become full lines for the purpose of denoting on which side of the line X–X they are. Note that 1 and 2 are on one side of X–X and 3 in the centre, whilst 4, 5, and 6 are on the other side.

On the metal sheet that will form the slant pipe draw the girth line X–X, and across this line, but at right angles to it, draw line G–G. At the point of intersection place the figure 0 on one side and 6 on the other. With the dividers space off (from line A–B) the distance between 0 and 1 on the slant-pipe semicircle. Convey this distance to the line X–X and mark off the space 0–1 on either side of 0. Convey the distance between 1 and 2 on the same semicircle and then 2 and 3. Remember that 6 and 0 are both on the same spot, both on the semicircle and on the line X–X; therefore repeat the process by spacing off 6 to 5 from the semicircle and transferring the distance to 6–5 on line X–X, the same with 5–4 and 4–3.

If you have made your drawing correctly, the repeated 3s should cover exactly the same spots on both ends of line X–X.

On the hopper elevation, space off from the centre line X–X the length 0 and mark off the line 0 the same distance on line G–G from 0, then mark the distance from X–X to 1 on the hopper elevation and transfer to line 1. Do the same with 2.

Give your attention to the other side of X–X on both hopper and girth line and mark off X–X to 6 along G–G from the point 6. Do the same with X–X to 5, X–X to 4. All the distances from X–X are to the joint line and *not the extensions* to the edges of the hopper. A free line through the marked-off lines will give the shape of the hole in the slant pipe.

The line 3*a* shown on the elevation of the hopper has been drawn to show the extreme length of the hopper joint line. It has not been found necessary to extend this line to that portion dealing with the hole in the slant pipe, as the existing lines are quite adequate.

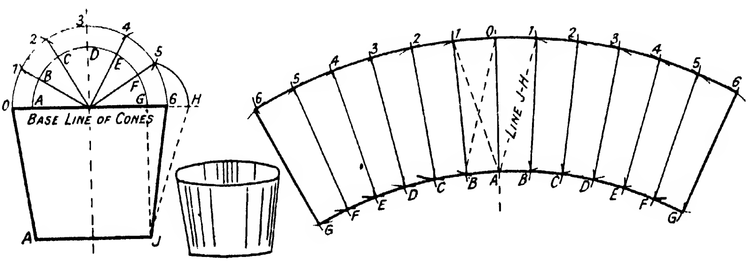


FIG. 20.—DEVELOPMENT OF CONE BY "LONG-MEASURE" SYSTEM

Development of Cone by "Long Method" (Fig. 20)

Some cones are of such very slight taper that, if any size at all, would take the whole floor of the workshop to lay out if the pattern were to be developed from the apex of the cone. For such work there is another method based upon triangulation. If three sides of a triangle are known, the triangle itself takes up a particular shape and one shape only. It is on this rule that the "long-measure" system is carried out.

In our example (Fig. 20) we have laid out the usual semicircles on the large base, and running up the dotted line J–G we have been enabled to draw the semicircle of the smaller end of the cone on the same line. There is no reason why the second semicircle should not be built up on the bottom of the elevation, excepting that it is more convenient to place it on the top along with the other semicircle.

The semicircles are divided into six equal parts, numbered and lettered as shown. With one leg of the dividers on the point G and the other on the point 5, describe an arc finishing at H on the extended base line. The distance J–H will give us the diagonal line with which to form our triangle and thus locate the correct positions of our points on the developed pattern.

The first thing to do in sketching out the pattern is to draw the line 0–*A*, which line will be the same length as 0–*A* on the elevation. From the point 0 develop the arc 0–1, and from *A* develop the arc *A–B* obtained from their respective semicircles. Set the dividers to the length *J–H* on the elevation, and with one leg on the pattern at 0 scribe an arc meeting the radius of the distance *B* from *A*. Transfer the leg of the dividers to *A*, and at the length *J–H* describe another arc crossing the smaller one at 1, exactly as shown in Fig. 20.

If the operator has more than one set of dividers, it is as well to set one pair at the length *J–H* and fasten them so that with the frequent measurings during the laying out of the pattern they cannot be altered. It is this long diagonal measurement that is so important in the correct development of the pattern. The same applies if you can set another pair of dividers to 0–1, and another pair to *A–B* on the periphery of the semicircles and lock them in position.

From the intersecting point 1 radius off *J–H* again, likewise from *B*. From point 1 mark off the length equal to 0–1, and on the intersection place the figure 2. From *B* mark off a distance equal to *A–B* and mark off *C*, and so on until all the twelve sections have been marked out, not forgetting to locate the point positions with the aid of the diagonal line *J–H* in every instance.

In actual practice it is not found necessary to draw lines, but only to mark off the various points, except in the case when the method is being used for the first time.

Square and Rounded Hoods (Fig. 21)

The square hood shown in the top of Fig. 21 presents little difficulty, and is arithmetically worked out as mentioned in a previous paragraph; but the average mechanic, especially when it comes to "square roots," is not particularly happy. The side measurements of the hood layout are generally known, because the hood has to cover a certain stove or hearth; therefore width and depth have first to be determined. It is the slope of the front that is mostly the unknown quantity. Without figures the 42 by 30 triangled side can be laid out to form one side of the pattern, and the part that will form the front portion is built upon it without in any way troubling about measurements at all. The line *W–W* can then be drawn parallel to the bottom edge of the hood and, passing through the corner of the first side, so determine where the 90° angled corner comes in the third side.

The lower sketch elevation and the resulting pattern is that of a similar hood, but with large rounded outer corners. In the example given it has been assumed that from *H* to *O* is straight. At right angles to the sloping front draw a line passing through the back corner. On the bottom line of the hood, produce the quarter circle and divide into three equal parts. As the portion from *H* to *O* is straight, the radius of this quarter-circle will be *E–H* with the centre at *H*. Draw lines from the periphery of the quarter-circle to meet the edge of the hood as shown. Prolong the lines parallel to the sloping front and measure off 3′–*F*,

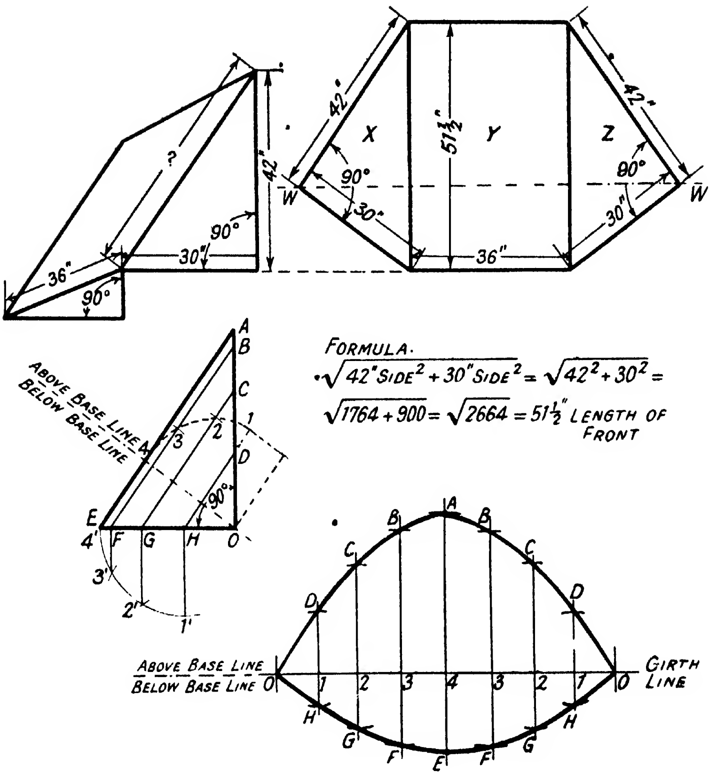


FIG. 21.—PATTERNS FOR SQUARE AND ROUNDED HOODS

2′–G, and 1′–H on the bottom line quarter-circle, and transfer them so as to form dotted apparent quarter-circle above the base line.

It may be thought that it is unnecessary to draw the lower quarter-circle, but if the reader will measure along the base line from 4 to H–1 it will be seen that the distance is much shorter than 4′–H along the bottom line of the hood.

The pattern is produced by first drawing the base line and at right angles drawing the line A–4–E. Space off along the base line (now the girth line) eight spaces equal to sections on the lower quarter-circle periphery and *not the lower edge of the hood.* On the lower side of the girth line measure off 4–E, 3–F, 2–G, and 1–H, on one side of the line A–4–E, and on the other side repeat the process. These measurements will be obtained from the dotted base line to the lower edge of the hood. Above the base line (now the girth line) space off 4–A, the

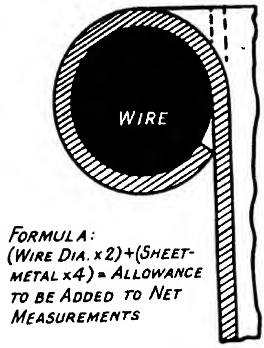


FIG. 22.—ALLOWANCE FOR WIRING EDGES OF SHEET-METAL ARTICLES

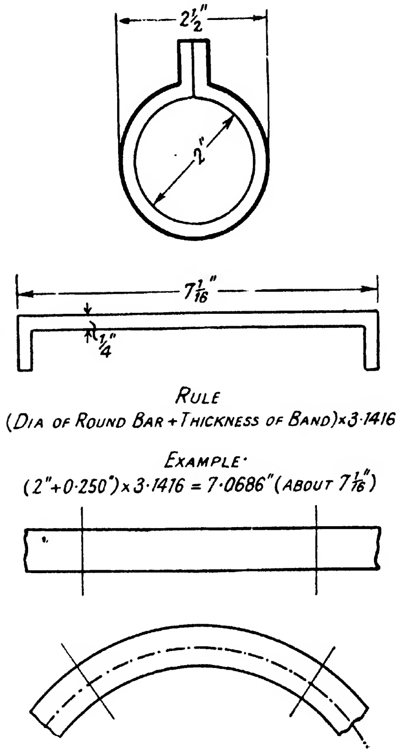


FIG. 23.—RULE FOR MAKING METAL CLIPS AND BANDS

length of which will be on the line 4–*A* from above base line to the top edge of the hood. The others, respectively, will be 3–*B*, 2–*C*, and 1–*D* repeated on both sides of line *A*–4–*E*. Freely drawn-in lines from 0 to 0 above and below the girth line will give the true shape of the hood.

Allowance for Wiring Edges of Sheet-metal Articles (Fig. 22)

The formula shown in Fig. 22 should be guide enough for all practical purposes, but an example may be of use: Assume a metal tray made from 20-gauge sheet steel has to be edged with $\frac{1}{16}$-in. wire. This resolves itself into $(0{\cdot}0625 \times 2) + (0{\cdot}0392 \times 4) = 0{\cdot}125 + 0{\cdot}1568 = 0{\cdot}2818$, or between $\frac{17}{64}$ in. and $\frac{9}{32}$ in. Whatever the diameter of wire or thickness of material, the same rule applies, and this is the extra length that must be added. Care must be taken to make very accurate measurements, otherwise the wire will not have sufficient material to hold it in place, or the ultimate measurement of the box will be incorrect.

Rule for Making Metal Clips and Bands (Fig. 23)

The average mechanic is often at sea when it comes to making a simple clip or band for a pipe, but if the following rule is observed, the clip should be a perfect fit. In the example (Fig. 23) we have a 2-in. bar with a clip ¼-in. thick.

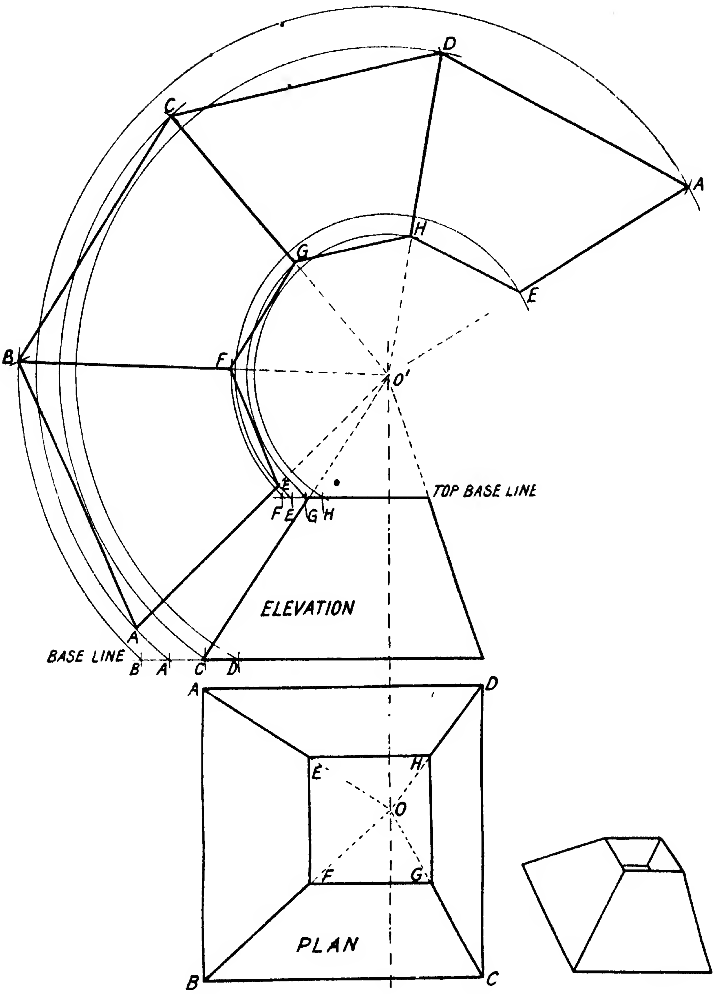


FIG. 24.—PATTERN FOR SQUARE TAPERED BOX WITH UNEQUAL SIDES

The calculation is based upon the fact that the only portion of the band that can be relied upon for correct measurement is the centre line of the band itself. Under the rule in Fig. 23 is a piece of straight metal with two lines through it at right angles. If the metal is bent, the imaginary lines will then be as the second sketch of the example, wherein the distance has remained constant on the centre line, contracted on the underside and expanded on the upper side. It will be seen that the centre line only is the place where all calculations must start. With a ¼-in, thick clip on a 2-in. bar. the actual diameter becomes 2¼ in.

Square Tapered Box with Unequal Sides (Fig. 24)

First draw the plan of the desired box (Fig. 24) and see that all the side edges, *A–E*, *B–F*, *C–G*, and *D–H*, meet at a common centre 0, otherwise it will not be possible to construct the box. Having made sure of the correctness of the design, then draw the elevation and extend the two sides to the point 0′. Extend the base line so that the edges 0–*E*–*A*, 0–*F*–*B*, 0–*G*–*C*, and 0–*H*–*D* can be spaced along it as shown at *B*, *A*, *C*, and *D*. On another base line extended along the top of the box, space out 0–*E*, 0–*F*, 0–*G*, and 0–*H*. With 0′ as the centre, draw circles equal to the places where the letters *B*, *A*, *C*, *D* intersect the base line. Then carry out the same process with the same centre, but using *F*, *E*, *G*, *H* on the top base line. At any convenient position draw the line *A–E* radiating from 0′ and starting on radius *A* and finishing on the smaller radius line E. This, of course, will be the edge of the box at *A–E*. With one leg of the

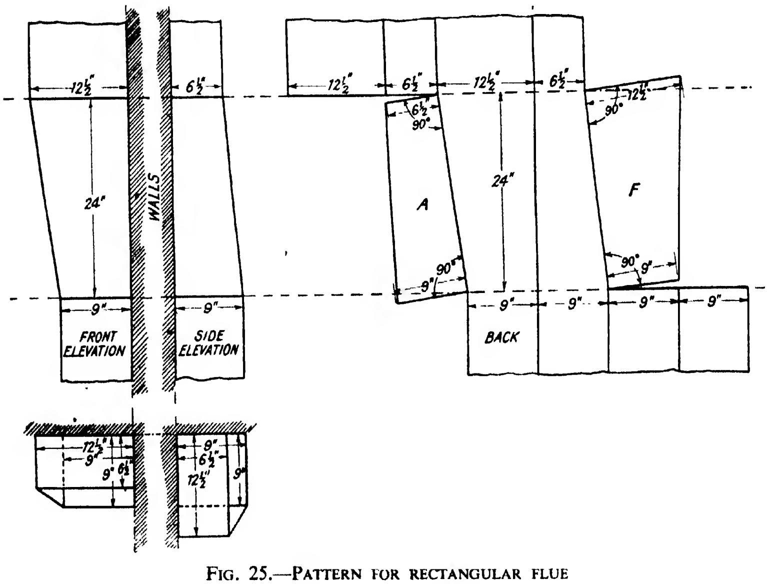


FIG. 25.—PATTERN FOR RECTANGULAR FLUE

dividers at the corner *A* on the plan, measure off *A–B*. Then set one leg on *A* on the end of the line drawn on the radius *A–E*, and measure off the point *B* on the radius *B*. Measure off the distance *B–C* on the plan and space *C* on the radius line *C*. The same with *D* on radius line *C* and *A* on radius line *A*. If lines are drawn from these points to the centre 0′ and the points *F*, *G*, and *H* marked off on the same lettered radius lines, the edges of the box can be drawn in. On connecting up the points *E–F*, *F–G*, *G–H*, and *H–E*, and forming the top edges of the box opening, they will all be found to be the same length, or should be so if the measuring has been accurate and the correct radius lines have been selected; that is, *E–F*, or *F–G*, or *G–H*, and *H–E*.

Rectangular Flue (Fig. 25)

Fig. 25 has been specially constructed to give some idea of requirements in buildings where air conditioning is installed. This drawing is based on a required change in shape, but retaining the same internal area. The bottom flue is 9 in. square, whilst the top part is $12\frac{1}{2} \times 6\frac{1}{2}$ in. The pattern has been so arranged that it can be cut out of one piece of plate and with as few joints as possible. The pattern layout is quite simple, especially with the back and one of the sides. The caution in this instance is not to forget to construct side *A* and front *F* at right angles to the sides immediately against them. By so doing it brings the edges back to square, otherwise the layout is quite simple, and is a very good example of the class of sheet-metal work which the general engineers' shop is called upon to carry out from time to time.

Blacksmith's Hood and Flue (Fig. 26)

The example in Fig. 26 is a further step in laying out patterns that are curved and have to meet snugly the flue that will be fixed. There is no difficulty in producing such a pattern if the instructions and rules are fully adhered to.

In the first instance, draw an accurate sketch of half of the hood plan. Draw a line at *C*, thus quartering the actual flue hole. Once again section off at *D*. The extreme ends of the rounded corner are then denoted by the dotted lines, the intersection producing a centre from which the dividers can be used to space off the edges of the hood as 2, 3, 4, and 5. Lines are then drawn through the flue centre from point 5 and the point *C* from 2. These lines will meet at the point *X*, and it is from here that a line parallel to 0–6 is drawn and on which is built the elevation as shown.

In other instances it has not been essential for the elevation to be definitely placed, but here the relative position of both plan and elevation have a marked effect on the correctness of the pattern.

Having drawn the elevation in its correct position, continue the line *A′*–6 until it intersects another line drawn from *X*. This line is parallel to 0′–0′ and will intersect *A′*–6 at *X′*. Using *X* as a centre, run radius lines from 2, 3, 4, and 5 to the base of the elevation at 2′, 3′, 4′, and 5′. Line 6–6 is not curved, as it already shows the true position of 6 on the half-elevation. From the points just mentioned run up lines to *X′*. From the half-plan mark off the distance 0–1

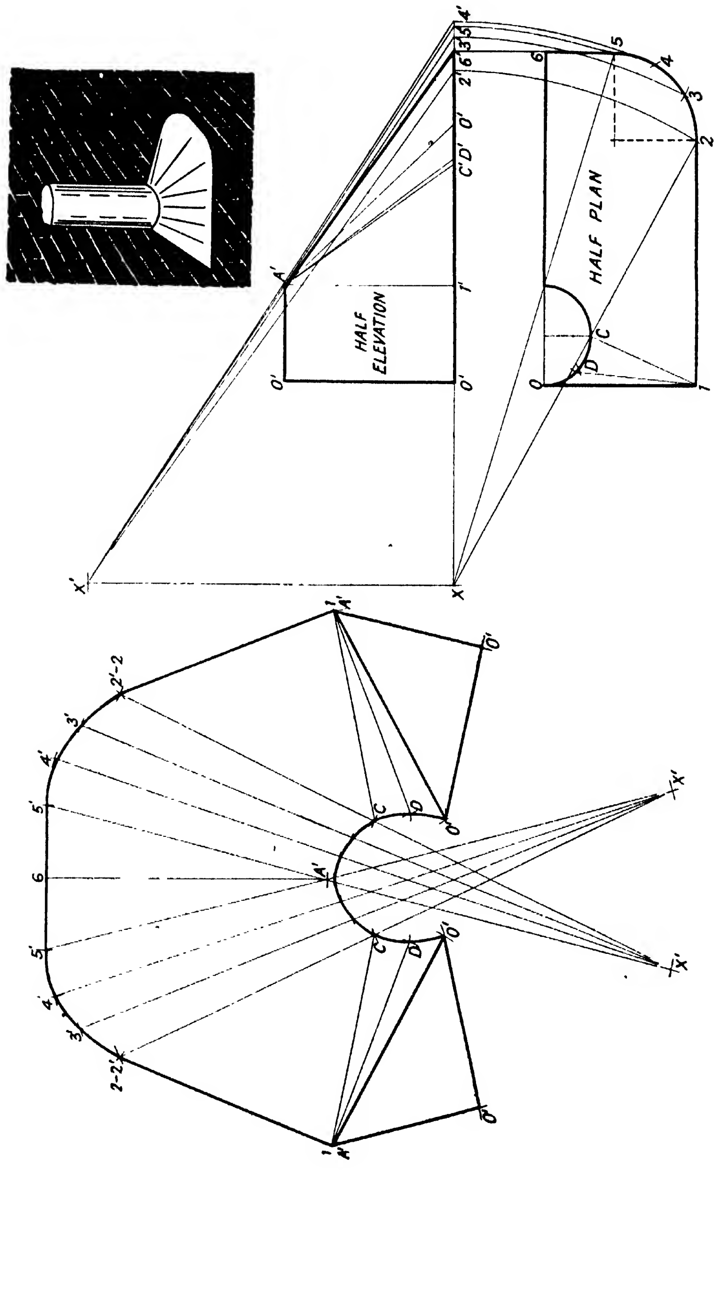


FIG. 26.—PATTERN FOR BLACKSMITH'S HOOD AND FLUE

from 0′ on the elevation to 0′ along the base, the same with 1–D and 1–C, and mark them D' and C' respectively. Draw three lines from A' to 0′, C', and D' respectively.

Forming the Pattern

In commencing the pattern, first draw a line equal in length to A'–6 on the elevation, and at right angles to this line on the point 6 draw another. Mark off on either side the distance 6–5, *taken from the half-plan.* Mark the points 5′. From the two points 5′ run down lines through the point A' and then open out the dividers and measure off from 5′ on the elevation the distance 5′–X', and transfer this value to the extended 5′–A' on the pattern. As there are two of each figure (one on either side of 6) we shall also have two points marked X' on the pattern. Set the dividers to 5–4 on the quarter-circle on the plan and mark off 4′ as done with 5′. Take the distance 5′–X' on the half-elevation, and from X' on the pattern intersect the radius drawn from 5′ and produce the definite point 4′. Carry out the same with 3′ and 2′.

We shall now have four lines radiating from each centre X'. Mark off the size of the hole in the pattern by distancing X' to line 0′–A' on the top of the elevation where the respective lines pass through the elevation of the flue.

It will be seen that the line X'–2′ on the elevation passes some distance away from the others through 0′–A'. Very carefully mark the distance at C on both lines on the pattern, as these points now become centres of the remaining vital measurements. At the points 2–2′ on the pattern set one leg of the dividers and radius a distance equal to 1–2 on the half-plan (be sure the measurement is taken from the half-plan). Having scribed the part circles, measure off A' to C' from the elevation. With one leg of the dividers on the point C on the pattern, intersect the part circle and draw a straight line from 1/A' to 2–2′. The same on the other side of the pattern. On reflection, it will be recognised that these straight lines will form the sides of the hood marked on the half-plan as 1–2.

Completing the Hood Pattern

At the points 1/A' on the pattern scribe off the distances A' to D' from the half-elevation. Set the dividers to the distance C–D on the semicircle representing the flue on the half-plan, and intersect the line 1/A' to D at D on the pattern. From 1/A' *again* measure off a point equal to A'–0′ from the half-elevation, then space from D on the pattern the distance D–0 from the half-plan, after which mark both spots 0′. From the points 0′ on the pattern radius off the lengths 0′ to 0′ from the elevation. Returning to 1/A' on the pattern, intersect the last lines with the distance 0 to 1 from the half plan.

Connect up the points of intersection, and the result will be the complete hood with back plate that will only need joining down the centre.

SHEET-METAL TOOLS

The tools used for working sheet metal are hand- and power-operated cutting and forming tools, and it is proposed in the next few pages to give a brief description of the various types.

HAND-OPERATED CUTTING TOOLS

Guillotines

Guillotinės, usually treadle-operated machines, are fitted with a long straight blade, used for making straight cuts up to approximately 4 ft. in length on metal not exceeding 18-gauge thickness.

Snips

Several types of snips or shears are to be encountered in sheet-metal work, each being intended for use on a different class of work. Straight snips are used to make straight cuts and also for cutting outside curves. Bent snips are specially

FIG. 27.—CUTTING METAL SHEET TO SIZE ON TREADLE GUILLOTINE SHEARS
(*Tecalemit, Ltd.*)

intended for cutting internal curves, and Universal snips, as the name implies, are intended for universal use, the blades being thin and "backed off" to allow an easy passage over them for the metal. These are used for cutting any curve or shape in flat work, and may be obtained to cut either right hand or left hand.

French snips consist of straight snips with off-set blades and "swept" cutting edges, and are intended for cutting shaped panels, being manufactured in both right- and left-hand styles, so that panels can be cut *in situ*. The correct hand to use for any job is that which will curl the waste metal in the opposite direction to the curve of the panel.

Jewellers' bent snips are light bent snips which are extremely useful for

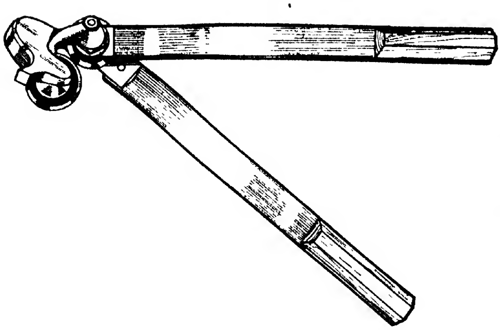


FIG. 28.—"EZISHEER" SHEET-METAL SCISSORS

Capacity up to 16 gauge. (*Buck & Hickman, Ltd.*)

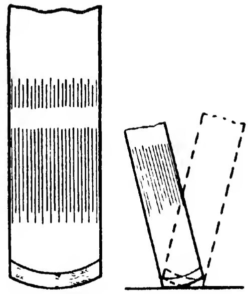


FIG. 29.—USING CHISEL FOR CUTTING SHEET

Note rolling motion of chisel.

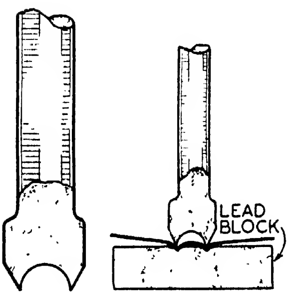


FIG. 30 (*left*).—HOLLOW PUNCH FOR CUTTING OUT ROUND HOLES

Showing distortion of sheet produced by this method.

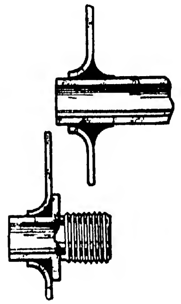


FIG. 31 (*right*).—SHOWING TUBE AND CONNECTION SOLDERED IN PUNCHED HOLE

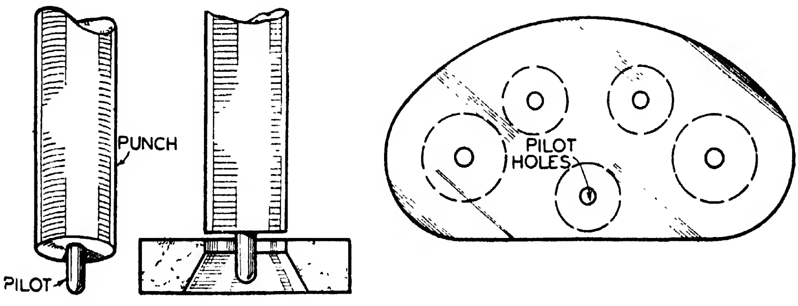


FIG. 32.—PUNCH AND DIE FOR USE IN FLY PRESS

On right—tank baffle with pilot holes drilled to allow each hole to be quickly located and punched in correct position.

"cutting in" aircraft cowling, and for cutting holes in light-gauge metal and similar light work.

Hand-lever Shears

Hand-lever shears are light toggle-jointed bench shearing machines for cutting metal up to 10-gauge thickness (⅛-in.), this gauge being too heavy to be conveniently cut with snips.

FIG. 33.—HAND-OPERATED FLY PRESS SUITABLE FOR LIGHT STAMPINGS AND PUNCHINGS

(Marketed by George Cohen, Sons & Co., Ltd.)

Using Chisel for Cutting

In the absence of suitable shears, the ordinary cold chisel can be used for cutting heavy sheet and plate metal, and also for cutting out holes to a finished size. The edges should be ground slightly convex (Fig. 29), so that the corners do not "dig in" and to enable a line to be followed by rolling the chisel edge along the line as the cut progresses.

Hollow Punch

A hollow punch is a circular cold chisel used for cutting out round holes in sheet metal, the work being laid on a lead block (Fig. 30). Unfortunately, the cutting action stretches the edge of the hole, thus producing a rounded burr which makes this method undesirable for many classes of work. However, if fittings are to be soldered in the hole, the burr is of definite advantage, as it gives a larger area of metal on which to solder (Fig. 31).

Punch and Die

The most suitable method of producing a hole without a burr is undoubtedly by the use of a punch and die mounted in a fly press (Fig. 33) or other suitable machine. It is usual practice to have the punch made with a pilot pin turned on the end, so that it will engage in small pilot holes drilled in the centre of the holes to be cut. By this means each hole is quickly located and punched in the correct position (Fig. 32).

POWER-OPERATED CUTTING TOOLS

Rotary Shears

Rotary shears are entirely different from any type previously mentioned, as they consist essentially of two hardened-steel wheels attached to geared

shafts, arranged so that the cutting edges slightly overlap, thus producing a shearing action. A clean cut of any desired length can be obtained, but the width of the work is limited by the distance from the wheels to the frame, this space being known as the "throat." These machines are used for cutting ribbons, square internal holes, and similar applications.

Throatless Rotary Shears

To overcome the limitations imposed by the frame of the slitting shears, a throatless shearing machine has been built with a frame so designed that the metal passes on either side, in the same way that it passes over the back of the blades of universal snips. The bottom wheel is serrated, and thus cuts an impression in the waste material, also feeding the metal through the wheels with a rack-and-pinion action. The machine is extensively used for cutting shaped panels from complete sheets, but as the work is fed through the wheels (and guided) by hand, it cannot be regarded as a precision cutting tool, except when used by highly skilled operators. Its main use is to cut the panels to shape roughly, leaving sufficient material on the edges to allow for trimming with snips.

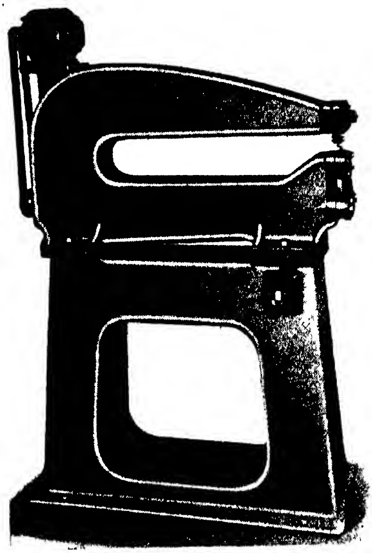


FIG. 34.—POWER-OPERATED SHEAR-TYPE NIBBLER FOR CUTTING MILD STEEL UP TO 14 S.W.G. (*F. J. Edwards, Ltd.*)

A circle cutter is a rotary shearing machine with provision made for carrying the work about an adjustable centre. By locking the distance between this centre and the cutting edges, a circle of any desired radius may be cut by merely revolving the wheels, the operation becoming automatic as the metal feeds past the wheels.

Shear-type Nibbler

The shear-type nibbler is usually a small, power-driven machine used for rapidly and accurately cutting metal up to 14-gauge thickness. Actually this is a type of short-stroke power shear, fitted with a rapidly oscillating cutting blade, so that each stroke makes a cut of approximately $\frac{1}{8}$ in. in length. The speed of the blade is between 1,200 strokes and 1,600 strokes per minute, and the linear cutting speed is in the region of 6 ft. per minute. Usually the metal is fed "free-hand." The machine can be used for all cutting-out purposes, and in particular

is largely used for cutting out from the sheet motor-body panels and similar work. A clean edge, which does not require further treatment, is produced by the blade. Fig. 34 shows a shear-type nibbler for cutting mild steel up to 14 s.w.g.

Punch-type Nibbler

For metal from 16- to 10-gauge thickness a punch-type nibbler is often used, consisting of a small punch and die which punches out a straight-sided hole (Fig. 35). The punch oscillates at 300 strokes to 350 strokes per minute, and as the work is fed through the machine, the holes overlap to cut a straight-sided slot, which leaves a clean outline. It is usual practice to clamp a thick pattern to the work and guide it to the required curve by keeping the edge of the pattern bearing against the punch. Heavy-duty nibblers work on similar principles to the machine described above, but cut a round hole of about ¼-in. diameter, being used for plate up to ¼-in. thickness. The serrated edge left by the tool must be cleaned up with a file. A pilot in the centre of the punch regulates the depth of each "bite," these being made at the rate of 120–150 per minute (Fig. 36).

Punch- and Shear-type Nibbler

The machine shown in Fig. 37 will cut mild steel up to ⅛ in. thickness, and can be used with either shearing cutters or nibbling punch and die. For inside and outside cuts with the contour of the shape consisting of fairly long straight lines or sweeping curves, the shearing cutters are used. The nibbling punch and die is used when the shape calls for small radius corners or is in any way complicated. The shape required to be cut can be scribed on the sheet for the operator to easily follow the line, or when nibbling, a template can be used, ensuring that each piece cut is identically the same. The latter method is useful when cutting blanks, which, owing to their size and quantity, do not warrant the high cost of a press and tools. The template can be of wood or metal and fixed in position on the sheet by small clamps.

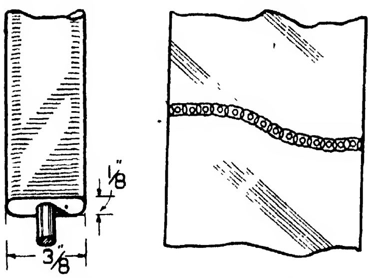


FIG. 35.—PUNCH-TYPE NIBBLER TOOL FOR CUTTING METAL FROM 16- TO 10-GAUGE THICKNESS

Showing how overlapping holes produce a continuous cut.

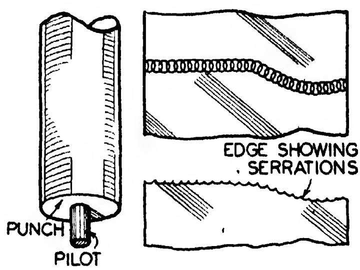


FIG. 36.—HEAVY-DUTY PUNCH-TYPE NIBBLER TOOL FOR CUTTING PLATES UP TO ¼ IN. IN THICKNESS

The serrated edge left by the tool must be cleaned up with a file.

A circle-cutting device can also be used with this machine, enabling perfect discs and rings to be cut up to 42 in. diameter, and segments up to 34 in. radius.

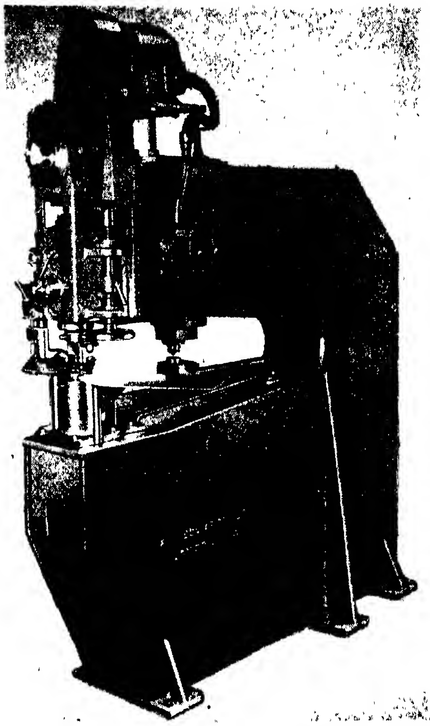


FIG. 37.—PUNCH- AND SHEAR-TYPE NIBBLER FOR CUTTING MILD STEEL UP TO $\frac{1}{8}$ IN.
(*F. J. Edwards, Ltd.*)

Guillotine Shearing Machines

Power-operated guillotine shearing machines are used for cutting metal sheet of various lengths up to $\frac{1}{4}$ in. thickness.

The machine shown in Fig. 38 will cut mild-steel sheet up to $\frac{1}{8}$-in. thickness. The heavy alloy-steel blades have 4 cutting edges giving straight, clean, accurate cutting. The length of the blades are $97\frac{3}{4}$ in.

Gang Slitting Machines

These machines are used for cutting either sheet or strip, using feed tables with various cross-cutting attachments for the former and coiling drums for the latter. The number of cutters and widths of spacers can be varied to suit the particular job in hand.

The medium-gauge gang slitting machine illustrated in Fig. 39 will cut mild steel up to 8 s.w.g. The maximum number of cuts in maximum thickness is 6. The width between guides on this standard machine is 36 in.

HAND FORMING TOOLS

The hand tools most commonly used for shaping sheet metal are hammers, mallets, and bench tools of the anvil type, over which the material is formed to shape. These latter are known as stakes, and are usually named after the particular use to which they are put, or after objects which they resemble. The stakes are provided with tapered square shanks, to fix into square holes cut in the bench, or sometimes they are made to fit in the end of a mandrel.

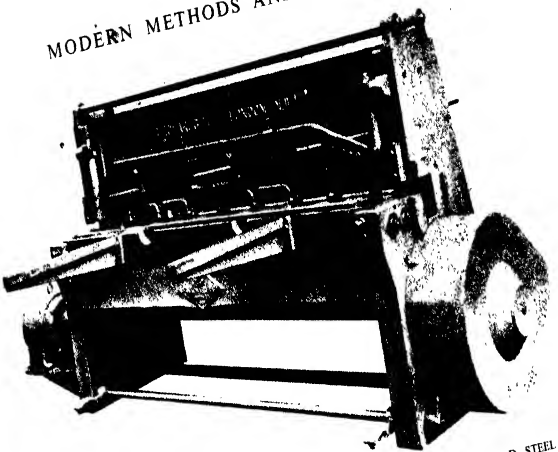


FIG. 38.—POWER-OPERATED GUILLOTINE SHEARING MACHINE FOR CUTTING MILD STEEL UP TO $\frac{1}{8}$-IN. THICKNESS (*F. J. Edwards, Ltd.*)

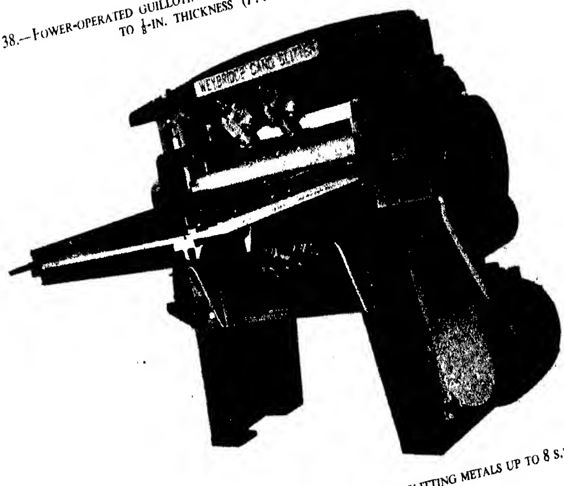


FIG. 39.—POWER-OPERATED MEDIUM-GAUGE GANG SLITTER FOR SLITTING METALS UP TO 8 S.W.G. (*Marketed by George Cohen, Sons & Co., Ltd.*)

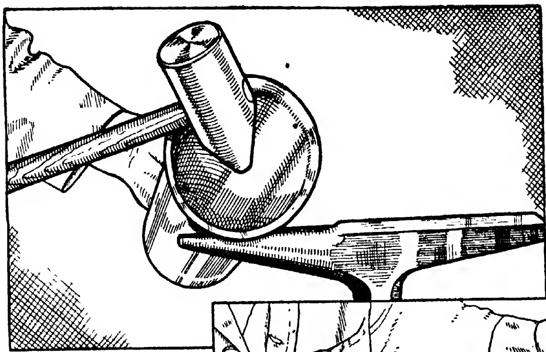


FIG. 40 (*left*). — FORMING FLANGE ON COPPER PIPE —FIRST STAGE

Using hardwood mallet on rounded portion of bick iron until sufficient metal is stretched outwards.

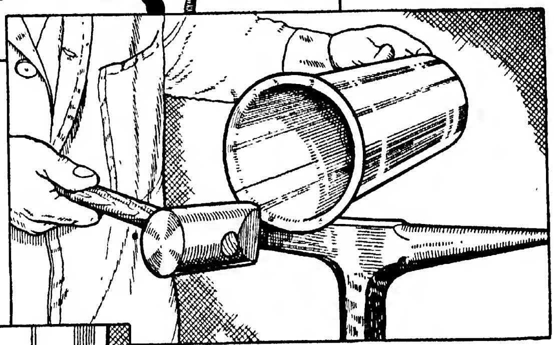


FIG. 41 (*right*).— FORMING FLANGE —SECOND OPERATION

The pipe is then placed on the square edge of the bick iron and gradually worked back flat, using the wedge-shaped mallet.

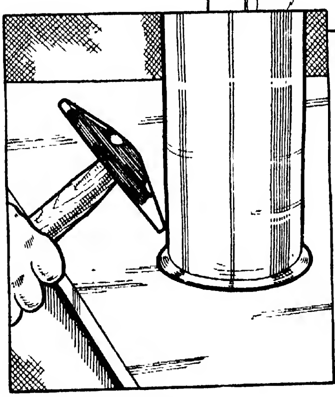


FIG. 42 (*left*).—FORMING FLANGE — FINAL OPERATION

A paning hammer being used to work down the neck of the flange against the pipe and to remove any irregularities.

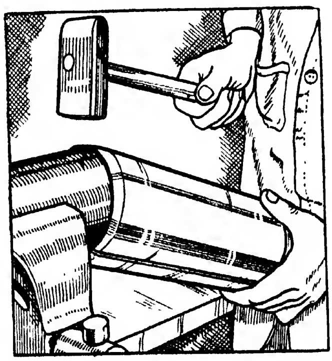


FIG. 43 (*right*).—SHRINKING A SPIGOT OR SLIP-IN END ON PIPE

The pipe is held at an angle to the mandrel and, using a mallet, the pipe end is worked over in ripples to form a taper. The ripples are then gradually worked out.

Hammers

Of the hammers, the most useful shape is the "square-faced" type, weighing 12–16 oz., having two flat faces, one circular and the other square. This is used for wiring, planishing, and all purposes where the metal is most suitably worked with a flat-faced hammer.

A planishing hammer is used for "finishing" panels by hammering them on a piece of shaped metal known as a "head." The weight ranges from 8 oz. to 16 oz. for use with sheet metal, and up to 3 lb. for plate setting. The faces of the hammer are round and, in comparison with the weight, fairly large. For sheet-metal work the usual diameter is between 1 in. and $1\frac{1}{2}$ in., one face being perfectly flat for planishing convex surfaces, whilst the other is curved slightly outwards to enable its being used for working from the inside of shaped panels or on flat surfaces where it would be difficult to strike a truly flat blow with the flat face of the hammer. In order to impart a good surface finish to the metal, the hammer faces should be always polished and smooth, this usually being done by occasionally rubbing the faces on a hand buff, consisting of a piece of soft leather tacked on to a wooden backing or mandrel. Crocus powder or other suitable polishing powder is sprinkled on the leather. A polished hammer will impart its polish to the work with every blow, and, conversely, every blemish on the face will be imprinted on the work.

The faces of a stretching hammer are rounded in one direction and straight in the other, the action being to displace metal in the form of a shallow trough, the metal so displaced extending the surface in one direction only. Principally, this hammer is used for stretching flanges, but it is useful for all inside shapes requiring stretching in only one direction. In certain cases, where the hammer shaft prevents the use of the standard stretching hammer, a special "two-way" type is used with one face across and one face in line with the shaft.

Blocking hammers are a group of hammers used for shaping sheet metal (particularly tinplate) on a wooden block, consisting usually of a section of a tree trunk with depressions of various depths in the end, the metal being beaten to shape in one of the depressions with a suitable hammer. Usually the weights of the hammers are between 1 lb. and 5 lb., and the two faces are convex, with rounded edges.

Hollowing hammers are used in a similar manner, but are provided with large hemispherical faces on a long head, in order to provide the necessary clearance when shaping deep articles.

Studding hammers are light and long-headed, being used to form local depressions in a larger job.

Paning hammers are specially designed for paning down the edges of joints situated in confined positions (e.g. close to the wall of a cylindrical article) and also for tucking metal behind a wire so that a neater finish can be obtained on larger wiring jobs.

Mallets

Boxwood mallets are used for operations where it is desired to avoid stretching or contracting (known as tucking) and also for wiring. Bossing

mallets are egg-shaped, and are used for shaping soft metals (such as aluminium) on a sandbag and also for stretching over rounded edges in concave curves (e.g. turning in the lights for motor bodies).

Mandrel

The most useful of the bench tools is the cast-iron mandrel, consisting of a bar approximately 4 ft. in length, one end having a rounded top face for shaping rounded jobs and the other a flat top face, with slightly tapered sides and end, this end being used for shaping square work. A square hole in this latter end is provided to hold small interchangeable heads or blocks of shaped metal.

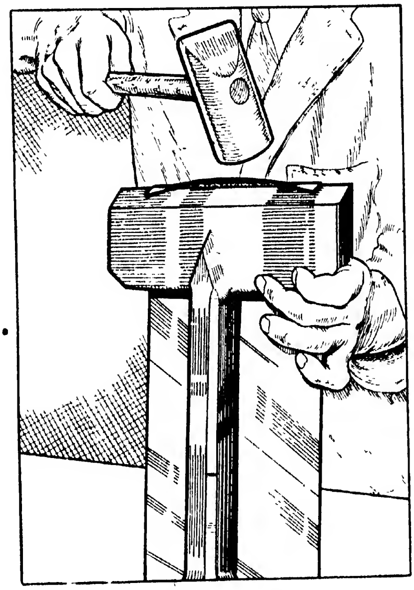


FIG. 44.—USE OF THE HATCHET STAKE

Showing how the edge of a small sheet of metal is turned in readiness for a welted or grooved seam by using a hatchet stake.

Bench Anvil

The bench anvil is a heavy bench tool having a flat face of D shape, and is used for general hammered work on flat surfaces.

Stakes

The anvil stake is a lighter form of the bench anvil and is used for similar work.

Bick irons, sometimes known as beak irons, resemble a blacksmith's anvil in appearance, but are lighter, longer, and more slender.

The square end is used for forming channels, narrow boxes, etc., while the "beak" is used for forming round tapered work.

Side stakes, known also as pipe stakes, consist of a round bar attached at right angles to an upright support. These are used for small round forms, whilst the end, which is cut off at an angle, is used for turning the edges of discs and similar articles in preparation for wiring and jointing.

Funnel stakes, as the name implies, are used for forming funnel-shaped articles, and consist of a half-conical section of steel attached to an upright support.

The extinguisher stake is a smaller edition of the bick iron, and was originally used to form the cones used for candle extinguishers, but is now employed for

forming small funnel-shaped and conical sections, and has, in addition, a useful narrow flat face.

Crease irons are provided with a rectangular face, semicircular grooves of various radii being cut across one half, while the remainder is left flat. The corners of pans and trays can be conveniently creased, and wired edges, etc., set on the grooved end, while box sections may be formed on the plain end.

Hatchet stakes consist of sharp-edged stakes, used for forming edges on work with straight sides or with inside curves which are sharper than a right angle. This tool is useful for work whose shape or position prevents the use of a folding machine, such as sharpening up rounded bends and forming the sides of boxes, trays, etc.

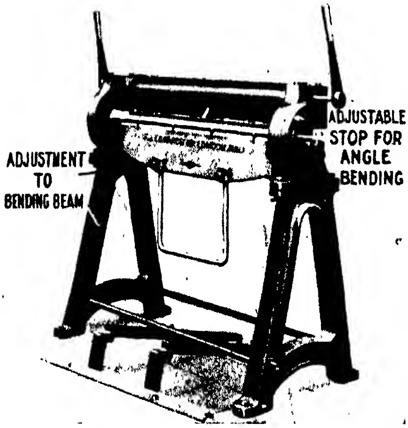


FIG. 45.—ANGLE BENDER OR CRAMP FOLDER

Note the four slots in the bending beam to clear the front hook guides, and also the back guide, dismantled, on the floor. (*F. J. Edwards, Ltd.*)

Half-moon stakes are curved, sharp-edged stakes used to form the edges on outside (convex) curves, discs, etc.

The dripping-pan stake and round-bottoming stakes are flat square-faced and flat round-faced stakes respectively. They have many uses apart from those for which they were originally designed, including edge forming and seaming square and round articles, as well as general use where a flat-faced tool with plenty of clearance is required.

Panel Heads

Panel heads are convex blocks of steel or cast iron fitted with square shanks to engage in a square hole in a wooden mandrel or horse. They are made in various sizes, shapes, and contours for forming and planishing the varied shapes into which sheet metal can be beaten, and are not standardised to the same extent as the bench tools. Panel heads are named from their shape or use, such as a raising head (used for shaping panels by planishing with a hammer), oval head, long head (from the shape), wing head (from its uses), etc. For tucking the edges of a panel when forming the shape, a head should be used which is flatter than the shape of the finished panel, and when planishing, a head which conforms to the shape of the job as nearly as possible (but slightly more convex) will give the smoothest finish.

The machines used in forming sheet metal include folding and bending machines, wheeling machines, bending and swaging machines, etc.

BENDING AND FOLDING MACHINES

The essential factor in producing a clean bend on sheet metal is that the edge or blade over which the metal is bent should be straight, smooth, and fairly sharp (a small radius is necessary to produce the bend), and that the pressure applied to bend the metal over this edge should be equal throughout the length of the bend.

Angle Bender or Cramp Folder

The most generally used machine for bending sheet metal up to 16-gauge thickness is the angle bender or cramp folder (Fig. 45), consisting of a clamp to which is attached the blade around which the metal is bent. This is operated by a hand lever fastened to an eccentric, to apply the necessary pressure to clamp the work to the bed of the machine in order to prevent movement while bending is in progress. The actual bending is done by swinging up the front part of the bed on a hinge centre, in line with the bend.

In practice it is only necessary to clamp the metal in the machine so that the edge of the blade coincides with the line on which the bend is to be made, and then to swing the bed up to the required angle, which may be anything from a "set," i.e. a very small angle, to 20°. This is the first stage in the production of a "double-edge finish" and an edge used for wiring.

Provision is made for repetition work by the fitting of a guide at the back of the machine for bends of more than 4 in., and hook guides, running in slots, in the front of the machine for small bends occurring near the blade. These front guides are let into dovetail slots, where they slide for adjustment, this being made independently on each hook by means of a knurled handscrew situated at the rear of the bed. In use, the hooks (usually only two are required, one at each end of the work) are set to stop the edge of the sheet at a predetermined distance from the bend line. The work is fed in from the rear until it engages the hooks, and is then cramped and folded.

The back guide, used for bends occurring too far from the edge to be dealt with by the front guide, consists of two arms with a T-slot running throughout their length. Across these is bolted the guide, which may consist of a cast-iron bar fitted with extension lugs to bring the guide face close up to the back of the machine, or it may simply be a length of angle iron bolted to the T-slot. The sole function of this guide is to stop the edge of the sheet at a definite distance from the blade when the bend is made. An adjustable stop is also fitted, so that the bed can be set to swing to the same predetermined angle each time. This "angle stop" consists of a collar and bolt, sliding in a T-slot shaped in the form of an arc, the slot being fitted on to the end of the machine. A lug on the swinging bed engages with this collar, and is thus prevented from further angular movement.

Hand-operated cramp folders are usually from 3 ft. to 4 ft. in length, but are often made with open ends, so that bends longer than the bed can be made by moving the work and making the bend in two or more operations. Power-driven machines are built to deal with $\frac{1}{8}$-in. plates up to 10 ft. in width.

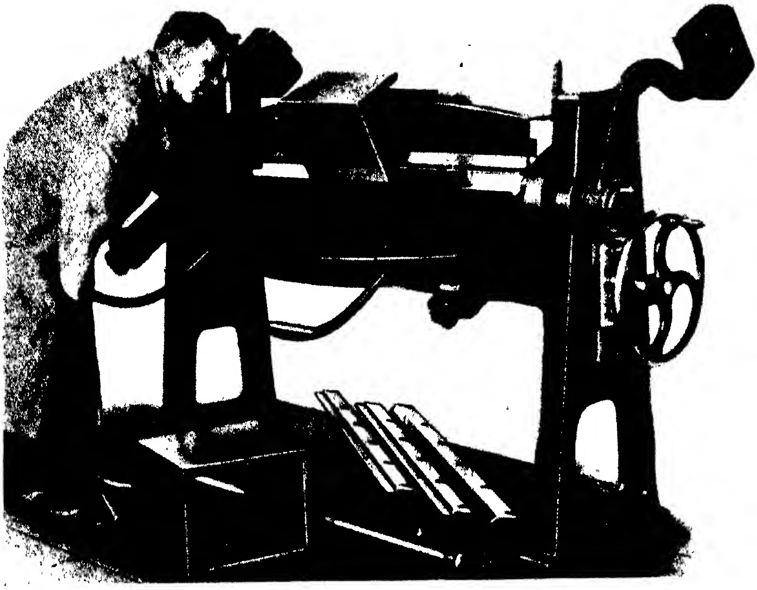


FIG. 46.—UNIVERSAL SWING-BEAM FOLDING AND BENDING MACHINE

Note the screw-operated cramping beam, counterbalanced bending beam blades for square bends and bends of small radius, and the roller attachment for bends of large radius and tubes.

Adjustment is provided for bends of various radii and thicknesses of metals by raising or lowering the swing bed with two thumbscrews. For sharp bends on thin metal the bed is brought up level with the blade, whilst for thicker sheets or larger radii the bed is lowered so that it describes a small arc around the edge of the blade when it is swung up. For occasional radiused bends it is general workshop practice to wrap a piece of sheet metal around the blade, to "round off" the edge over which the metal is bent. For repetition work on radius bends the standard blade should be replaced by a special blade machined with the correct radius. It is not essential for this blade to extend the whole width of the machine, so long as it extends a short distance over both sides of the work.

Larger angle-bending machines have provision for bending radii by inserting rollers in the front edge of the clamp, which is operated by a handwheel and vertical screws, in order to give the greater pressure required for longer bends.

Power-driven Angular Bending Machines

One type of power-driven angle bender utilises a top cramp blade of narrow V-section, with bending beams on each side, giving a range of angles between

180° and 35°. Swing ends are fitted to enable work which has been folded to closed or intricate shapes to be withdrawn from the end of the machine, to eliminate the distortion caused by taking it out from the front or rear. This type of machine is made to deal with plate up to $\frac{3}{32}$ in. thick by 4 ft. wide, whilst the largest machines will bend $\frac{1}{4}$-in. plates up to 12 ft. in width.

Swing-beam Folding and Bending Machine

Another type of machine is the universal swing-beam folding and bending machine (Fig. 46), which is a heavy-duty hand machine with a counterbalanced swing beam. The capacity is 4 ft. by 14 gauge, and it is supplied with a series of cramp blades giving square and radiused bends, and a stepped blade giving clearance at the back for folding narrow channels and moulding sections. An

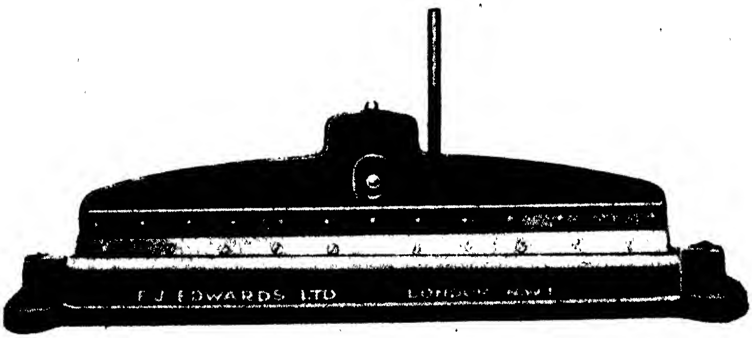


FIG. 47.—ROLLER-BED FOLDING MACHINE

interesting roller attachment is supplied, around which metal may be formed into a large radius bend, or by moving the metal around the roller during the operation a complete tube can be obtained in three operations.

In using bending machines for compound bends, skill and care are necessary if a true shape is to be obtained. The bends are worked in such order that one bend does not prevent another from being made, and the thickness of the metal must be taken into consideration in order to obtain a true section. Because of their versatility, cramp folders are the most useful of bending machines for general work.

Folding Machines

Folding machines are used for folding edges of sheet metal up to 20 gauge, so that they are doubled back. These machines are made in various widths from 12 in. to 36 in., and are constructed so that they can be bolted on to the bench. Two different types are made, with either flat or roller beds, the former, which only has adjustment for the size of the fold, being mainly used for tinplate.

In addition to this, the latter type (Fig. 47) has an adjustment on the roller which can be made to act as a stop for bends not greater than a right angle and for the radius of bend or thickness of metal for edges folded right over. For sharp folds on thin metal the roller is brought up to the blade and set with just sufficient clearance to allow the metal to pass between the roller and blade. For thicker materials or rounder bends the roller is moved back from the blade, thus giving more clearance for the heavier (i.e. thicker) materials, and, by making contact with the metal farther from the blade, gives a rounded bend.

Unlike the cramp folder, the work is not gripped, but the edge is slipped into a slot between the bed and blade of the machine, made by separating them with packing pieces. The back of the slot is formed by the adjustable guide which extends past the packing pieces, as a series of fingers. The guide is adjustable and slides backwards and forwards on a wide register to keep the end parallel with the blade. It is adjusted with a thumbscrew at the back of the blade and can be locked, with a setscrew, in any position.

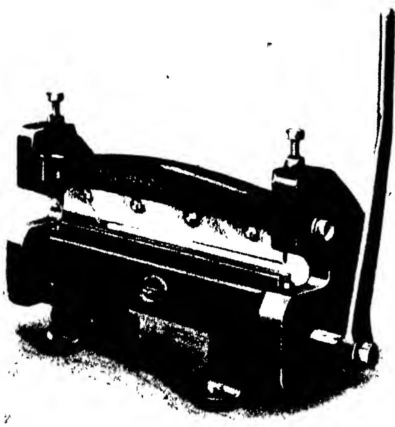


FIG. 48.—RIGHT-ANGLE BENDER

The whole of the back part of the machine hinges on large pins set in line with the edge of the blade over which the metal is folded. To use the machine a line is marked on the edge for the fold, and the edge is slipped under the blade until it rests against the guide, which is then adjusted until the blade edge coincides with the bend line. The guide is then locked in this position, and the handle attached to the back of the blade is pulled over, this having the action of pulling the edge over, while the roller rolls the body of the work over the edge which is held in the slot.

As the blade is returned to its original position the work is taken with it and may now be removed from the slot with a perfectly parallel folded edge. It is the most rapid method of folding edges up to approximately 1 in. (the maximum capacity), for work such as folded edges, finish folds for grooved joints, and small wiring (10 gauge or less).

Right-angle Bender or Bending Press

As the name implies, this machine is used only for bending right angles, and consists of a heavy frame mounted on either a stand or bench, with a top

arm which slides up and down between guides situated at each side. The arm is operated with an eccentric cam and hand lever (see Fig. 48).

The bed consists of a series of blocks, varying in length, so that they can be built up as required to make a block of any desired length, to fit between reverse bends. These are located on the bed with dowels, and have a V-shaped groove running through them, in which the metal is bent. The top blade has a V-shaped edge to fit the groove in the blocks, over which it is set absolutely central. The action of pulling the lever is to press the V of the top blade into the V of the blocks, thus forcing the metal between them to assume a right angle.

When the machine is used for boxwork, the two long sides are first bent into a channel shape, and a top tool that will just fit between the sides is used in place of the full-length blade, as it is necessary for the sides to have clearance on both sides of the top tool. A guide is provided at the rear of the machine for setting the distance between the edge of the metal and the centre line of the bend, for use on repetition work. When only one article is required, a line can be marked to show the position of the bend, although a small centre-punch mark at each end of the line will help to ensure greater accuracy as the line is obscured when the top tool is lowered.

Power-driven Machines

Power-driven machines of this type, having one-piece blades and blocks, are made to deal with sheets up to 12 ft. long by $\frac{3}{16}$ in. thick, the method of operation resembling the power press, to which it is closely related. Bending in the press is done with tools of similar form, i.e. the bottom tool is a block with a V of the required angle and radius machine in it, and the top tool is a blade of the same shape as the V in the bottom block, but slightly smaller to allow for the thickness of metal to be bent.

Bending Rollers

Bending rollers are used for bending sheet metal to curves of any desired radius, and for bending cylindrical work Hand-operated rollers are made in sizes from 12 in. wide (for 20-gauge metal) to 4 ft. (for 16-gauge metal), their construction and operation being as follows. Two rollers, geared together, feed the metal past a third roller fixed behind them, so deflecting it to the required radius. The feed rollers (i.e. the pair geared together) are adjustable, and should be set so that the metal can be just slipped between them when they are stationary, so avoiding stretching the edges and distorting the work, a fault which occurs when the rollers grip too tightly. The rear roller is adjusted with two hand-screws which raise or lower it to give the desired curve to the metal when it is rolled through.

To avoid forming a "flat" on the edge of the sheet remaining between the feed and bending roller, the sheet should be fed in until the edge reaches the rear roller and then the direction of rotation should be reversed, pressure being applied at the same time with the hand to the top of the sheet. This "sets" the end of the sheet to follow around the rear roller, so avoiding a break in the

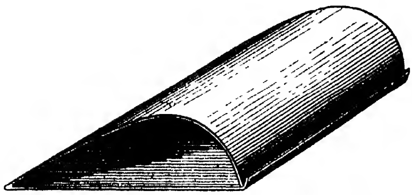


FIG. 49.—BENDING JIG FOR SHAPED PANELS

curve. A slip roller is fitted to some machines to facilitate the removal of closed cylinders by sliding them off the end of the roller (Fig. 2).

Panels which require to be set to a radius after wheeling may be rolled without distortion by widely separating the front rollers, provided that there is not too much "shape" (i.e. fullness) in the panels. Panels with a lot of shape must not be rolled, or the edges will be stretched and the shape lost.

Bending Jig

A bending jig is used when the shape in the panel is too full to permit rolling safely; this is usually made from sheet metal, long enough to extend past the ends of the panel, and shaped as in Fig. 49. The edge of the panel is slipped into the slot formed by bending up the bottom edge of the jig and setting is done by pulling over the shaped portion by hand.

Another method of producing radiused bends is by the use of a length of suitable round pipe attached to the bench by clips. The metal is pulled round the pipe by hand, using a piece of flat board behind it to keep an even pressure along the bend, thus producing a perfect bend of the same diameter as the pipe.

WHEELING MACHINES

Wheeling machines are one of the most useful tools to be found in the sheet-metal trade, and are indispensable where metal has to be beaten and shaped under commercial conditions. Wheeling is the smoothing of sheet-metal panels with steel wheels after the panels have been roughly beaten to shape. These machines are manufactured in a variety of sizes, and often vary in design for special classes of work, but the majority conform with the standard type illustrated in Fig. 50.

Standard Wheeling Machines

The framework is made from cast iron, and consists of two parts: (*A*) the main frame, and (*B*) the base or trestle. Between the frame is a steel shaft (*C*), running in roller or bronze bearings (*D*), to which is attached a flanged roller (*E*), the whole of which is kept in position by a collar and grubscrew (*F*). Usually this roller has a flat working face, but some panel beaters prefer it to be slightly convex. Immediately under roller (*E*) is fixed a perpendicular pillar (*G*), carrying a detachable roller, of which three different shapes are usually supplied with the machine (Fig. 50). The rollers are made of steel, the centres being bored out and the ends recessed to hold ball races, and through the centre is fixed a steel spindle

which, projecting from either side, is used to suspend the detachable roller in the carrier (*H*), parallel to the fixed roller (*E*).

When the machine is in operation it is necessary to adjust the distance between the rollers to suit varying thicknesses of sheets, this being done by raising the pillar (*G*). In the case of steel panels, considerable pressure is required, so the screwed shaft (*I*), fitted with a flanged wheel (*J*), is provided, enabling the whole component to be raised or lowered during operation by turning the wheel with the foot.

On the shaft (*C*) is a handle (*K*), which, while quite free from the rotation of the shaft, can, when necessary, be tightened and used to rotate the wheel (*E*), this being required when wheeling work of small dimensions.

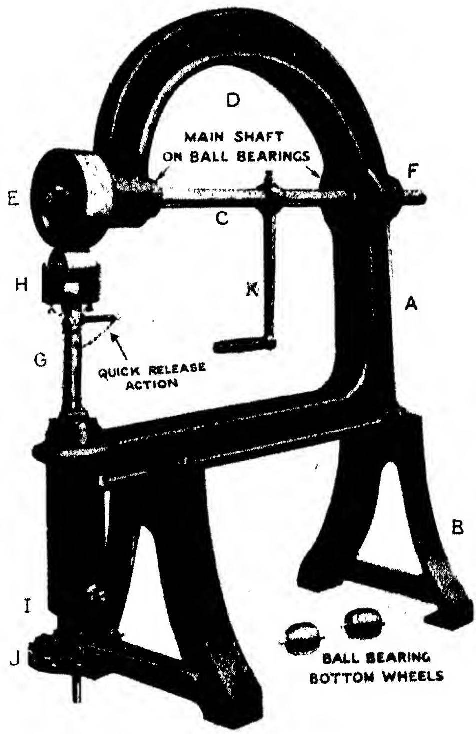


FIG. 50.—STANDARD TYPE OF WHEELING MACHINE
(*F. J. Edwards, Ltd.*)

Modern Types

Modern types of wheeling machines have in some cases taken an entirely different form, although the principle is unchanged. Some machines are made in pairs, arranged back to back on a common bed, thus saving considerable floor space. Again, in some works the machines are made from angle iron and bolted to the upright girders which form part of the construction of most workshops.

Many wheeling machines are now fitted with quick-release screws, making it unnecessary to unscrew (*J*) (Fig. 50) when a roller is to be changed. It has also been found that when certain articles, such as motor-car rear mudguards and aero-engine cowlings, are to be wheeled, there is not sufficient clearance underneath the machine. This has led to the introduction of a slightly different model (Fig. 51) for use with this special class of work.

FIG. 51.—WHEELING MACHINE WITH EXTRA CLEARANCE FOR CURVED PANELS
(F. J. Edwards, Ltd.)

Hints on Using

Many months of continual practice are necessary to become proficient in the use of wheeling machines, as so much depends on acquiring the "feel" of the work as it passes to and fro between the rollers. The work is first beaten until it is approximately the required shape, and is then slipped between the two rollers, being pulled backwards and forwards until all the mallet marks are removed.

The main difficulty experienced by the apprentice is the inability to keep the work in its original shape, and, unless the correct technique is used, the article very soon becomes distorted. This continual loss of shape can be counteracted by the skilled operator by varying his movements, which become more or less automatic after practice, and work can be carried out with a speed and surface finish only excelled by press work.

Increased Employment of Shaped Metal Sheet

Automobiles, railway engines, ships, and aircraft are all now streamlined, and as this necessitates the shaping of metal into curves to conform to aerodynamic standards and formulæ, very few straight or flat pieces of metal are now to be encountered in modern practice.

In motor construction the pieces of shaped metal are known as panels and are welded together to form larger sections. These are known in the aircraft industry as cowlings, but owing to rigid inspection at regular intervals the sections are kept fairly small, so that they can be easily detached.

Production of an Automobile Dome

The top part of a car is known as a dome, and to get this into the correct shape from flat pieces of metal it is necessary to beat the shape into the panels with a mallet until the roughly correct contour is obtained. After this stage the panel is made smoother by beating it between a mallet and shaped block of steel known as a "panel head." The next operation consists of finally finishing the panel on a wheeling machine by placing it between the top and bottom rollers and pushing and pulling it backwards and forwards until all dents or hollow places are smoothed away.

When wheeling, pressure is applied as required by raising the lower roller. If the contour of the panel requires raising, the bottom roller is raised, forcing

the work against the top roller, and after a few passes through the wheel the necessary raising will be accomplished. The panel should not be gripped too tightly and the hands should allow it to follow its own shape around the wheel.

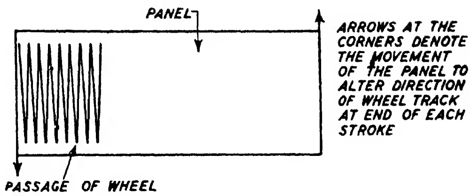


FIG. 52.—THE CORRECT METHOD OF WHEELING

From time to time it will be necessary to change the bottom roller to accommodate whatever shape is being formed, using the straightest wheel possible without rubbing the panel or causing flat places. It is very important that each backward and forward movement should be accompanied by alteration of direction, so that the rollers make contact with the panel in a different place at each movement (Fig. 52), at the same time making certain of covering the entire surface with the narrow track of the bottom wheel.

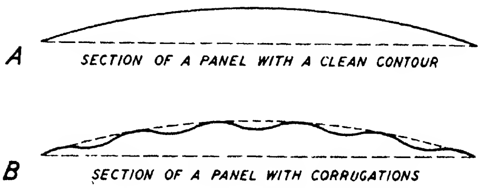


FIG. 53.—*B* SHOWS PANEL WITH FAULT KNOWN AS CORRUGATING

Wheeling Flat Panels

Flat panels or pieces of metal with little shape require the very minimum of pressure, and should be brought to the required shape as gently as possible, avoiding all undue pushing and pulling, otherwise a fault known as "corrugating" will be produced. This fault is not easily corrected by wheeling, as this has a tendency to make matters worse, and usually the only remedy is to reset the panel, by again using the hammer and "panel head." In some cases the corrugations can be removed by wheeling the panel diagonally across the wheel tracks responsible for the fault (Fig. 54).

Varying Contours

The contour of automobile door panels, and also certain aircraft cowlings, vary from one point to another, with the result that the curve is greater in

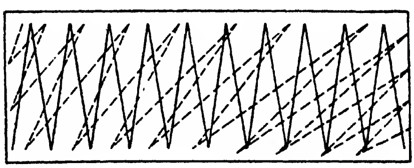


FIG. 54.—CORRECTING CORRUGATED WORK

Full lines denote path of original wheel track, and dotted lines denote diagonal path of correcting wheel track.

certain places. In order to obtain this variation it is necessary to run the wheel over the full parts more often than the surrounding places. As can be seen from the diagram in Fig. 55 the wheel is started in the spot where the fullness occurs, and after traversing to the bottom of the panel, the return is made over the same area already covered. The movement is continued to the top end, and in doing so the full place is wheeled twice the amount of the other portions, and to give a good surface finish it is customary to wheel lightly across the panel in a diagonal direction as shown in Fig. 55.

It will be found that panels with plenty of contour or curves can be subjected to considerably greater wheeling pressure without danger of corrugating the surface.

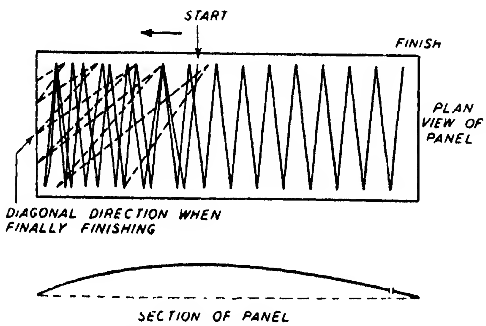


FIG. 55.—WHEELING A PANEL WITH A VARYING CONTOUR

Correcting Mistakes

Sometimes too much shape is wheeled into a panel, providing a faulty general appearance when joined to other sections. This unnecessary shape can be removed by turning the panel upside down and wheeling the outside edges, or in the case of door panels this reverse wheeling can be carried through the entire panel.

When wheeling large work an assistant may be required to hold one side of the panel, and in this case care should be taken to avoid roughness when pulling or pushing, as this will cause corrugation and unevenness of shape. The rule to remember when two operators are working on one panel is that each man should do his own pulling, but on no account should he push the panel as it passes from him.

When wheeling panels of a very full shape the passage of the wheel over the work should be controlled so that the starting and finishing point of each stroke does not occur in the same position, the panel being moved so that the raising of shape is done evenly and not by a series of lumps.

Other Uses for Wheeling Machines

Wheeling machines can be used for other purposes than that of smoothing sheet metal, and in workshops where automobile mudguards are made by hand (i.e. instead of pressing) it will be found that the wheel is used as a rotary press. Hand-made wings (or mudguards) are composed of sections welded together, the sections consisting of the valence forming the sides, and the main body consisting of the top and, in the case of front wings, an apron acting as an inside shield.

All the parts are beaten to their required shape, and after being wheeled smooth are welded together. During this latter process the metal has a tendency to warp and corrugate for a distance of approximately 2 in. on either side of the weld, owing to the uneven heating and contraction. To remove these corrugations by hand-beating is a long and tedious job, so to obtain quicker production the two wheels of a wheeling machine are made to a standard shape and are known as Van-der-Plas wheels.

The handle inside the frame is removed and fastened to the portion of the shaft protruding outside the rear of the frame, so that by turning the handle the top wheel can be rotated. Thus if the wing is placed between the wheels and the lower wheel is tightened, it can be passed between the rollers by turning the handle, two or three passes usually being sufficient to again produce a smooth and regular surface.

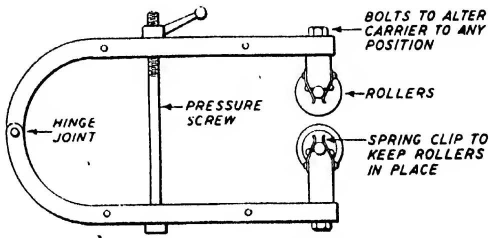


FIG. 56.—THE DENTERAZER MACHINE

Swaging with a Wheeling Machine

It may be noticed on modern cars that ornamental mouldings or swaging is used to improve the external appearance, and where cars are produced by hand this work is often done with the aid of a wheeling machine. Large panels cannot be swaged by ordinary swaging machines, owing to the lack of sufficient clearance between the back of the machine and the swage wheels, but by fitting wheels, shaped to the required form, into a wheeling machine, panels can be swaged to any design.

Denterazer Machines

A machine known as a Denterazer is to be found in many motor-body repair shops for smoothing out dents and hollows in bodies. In principle this machine is very similar to a wheeling machine, but is considerably smaller, and, instead of pushing the metal through the rollers, the machine itself is pushed and pulled over the work (Fig. 56).

The value of this can be appreciated for repair work, where, instead of having to dismantle the damaged portion, the denterazer can be run over the surface with a considerable saving of time and expense. To obtain good results it is necessary to beat out the dents roughly with a mallet and to remove all dirt from both inside and outside the damaged panel or wing, afterwards using the machine to provide a final smooth surface.

Sometimes the Denterazer is used as an ordinary standard wheeling machine for small work, by gripping one arm in a vice and passing the metal through the wheels in the usual manner.

BEADING AND SWAGING MACHINES

Swaging is the operation used to raise up moulding or beading on the surface of sheet metal, e.g. for motor-car bodies and similar work. This operation consists of forming the projections from the actual panel to be used on the body, etc., and is distinct from applied moulding where the form is made in solid metal, which is afterwards fastened on to the panels. Various methods are used to obtain these mouldings, but the most general method is to use a swaging machine fitted with suitable wheels.

The swaging machine shown in Fig. 57 consists essentially of a pair of shafts geared together and mounted in a suitable frame. Attached to one end of the shafts are rollers, male and female, shaped to produce a swage of the desired form. The top section of the frame, carrying the upper wheel and shaft, is hinged at the back and kept in upward tension by a flat spring. Vertical adjustment is provided to bring the wheels into mesh, and is operated with a small handscrew bearing on to the top arm. A small lever situated near the spur gears provides, through a face cam, for lateral adjustment, so that the wheels can be set to match up exactly when separated by the thickness of the panel.

An adjustable guide is provided to ensure that the swaged impression will

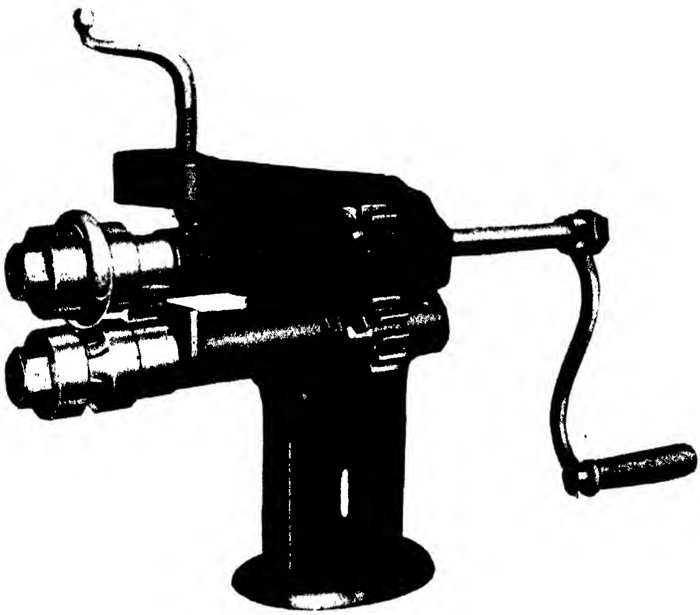


FIG. 57.—HAND-OPERATED SWAGING MACHINE

be true and parallel with the edge of the panel; that the impression will be symmetrical; and, thirdly, to ensure that for repetition work all the mouldings, etc., will be uniform.

Setting Up and Use of Swaging Machines

Swaging machines are usually supplied with a considerable number of wheels, suitable for forming beads of various widths and mouldings of various sections. Some machines are also supplied with wheels for slitting (to convert the machine to slitting shears) and wiring. To set up the machine for operation it is necessary to select a suitable pair of wheels to give the required section, and fit the male wheel on the top shaft and the female on the other, locating them with the keys fitted in the shafts and locking them in position with the recessed nuts, which are screwed with right- and left-hand threads so that they will tend to tighten during use, instead of working loose.

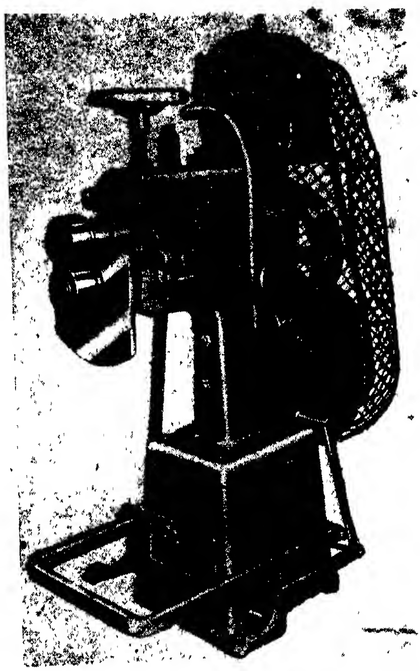


FIG. 58.—POWER-OPERATED SWAGING MACHINE FOR HANDLING METALS UP TO 14 S.W.G. (*F. J. Edwards, Ltd.*)

Having fitted the wheels, they are "lined up" by slackening the locking screw and adjusting the small lever at the rear of the frame until the wheels engage centrally with each other. It is important to bear in mind when selecting the wheels that there will be a thickness of metal separating them when in use, and sufficient clearance must be allowed, otherwise the wheels will mark the side of the moulding and be prevented from engaging to their full depth.

Next set the stop to the distance required between the centre of the moulding and the edge of the sheet. Adjust the top screw until the wheel forms a depression in the metal and then run it through the wheels; give another half-turn on the handscrew and repeat the operation until the wheel "bottoms," at which stage the swage will be fully formed. The object of forming the swage in gradual stages (usually three to four passes through the wheel are desirable) is to draw the metal up gradually, thus avoiding strain, which may result in splitting or distorting the panel.

Care must be taken, especially on the first run, to see that the edge is bearing on the guide and, due to the fact that the metal is drawn in from the sides during the swaging operation, the back edge only will make contact with the guide in subsequent runs, but this will be sufficient to keep the job true with the wheels.

Where heavy work has to be handled it is advantageous to have a metal-covered table alongside the machine, with the surface at the same height as the wheel centres, to take up the weight of the job. The operator can then feed the sheet through the wheels while an assistant turns the handle. Where such an accessory is available, it is only necessary to hold the sheet lightly on the table with the palm of the hand while the sheet slips under the hand, thus creating sufficient friction to keep the edge bearing on the back of the guide.

Uses of Swaging

Swages are used for a variety of purposes in sheet-metal work, such as decoration, stiffening section, and forming stops, shoulders, and rebates. Large flat panels, which are apt to be "floppy," are sometimes stiffened by running a half-round swage around the edges, this particular shape of section giving

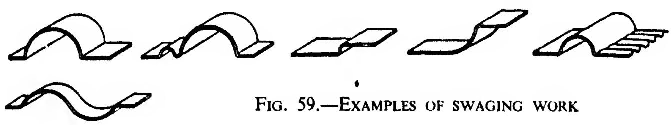


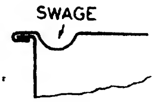
FIG. 59.—EXAMPLES OF SWAGING WORK

considerable extra lateral strength. Loose panels (i.e. panels which have been distorted by stretching in rollers or some other operation) can be tightened by swaging as the looseness is taken up in the extra metal required in the swage, and the neat half-round section adds to, rather than detracts from, the general appearance.

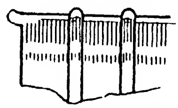
Large flat areas on some parts of motor-cars and coaches (e.g. the bottom of the foot well and running boards, floor and seat walls) are frequently swaged to give additional strength and to prevent "drumming" when the completed car is running on the road. Examples of the combination of strength with decoration by swaging is to be found in the design of circular articles, such as drums, dustbins, baths, etc. Swages are frequently used for location purposes on tanks, and on some aircraft tanks are used to form a channel to locate the holding-down straps, two swages, an exact distance apart, being used in this instance (Fig. 60). A swage, run around the top of a box or canister, is frequently used to act as a stop for the lid and to strengthen the top rim (Fig. 60).

Where the swage or bead is required to be on the extreme edge (as on a number plate, etc.), the metal should be swaged a short distance in from the side and the surplus trimmed off on the guillotine to form a clean edge. The side panels of a motor coach usually have a double swage running through them, the metal between the swages being painted in a contrasting colour to give the effect of a separate panel, which is often used as a background for

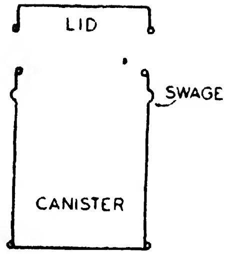
lettering (proprietor's name, bus destinations, etc.). The profile giving the positions of these swages is shown on a board, and the whole set of panels is run through the wheels at the same setting to ensure uniformity.



For tank end location.



For locating holding-down straps.



Swage round top of canister.

FIG. 60.—USES FOR SWAGING

Decoration for Cars

The swage is a very important part of the decoration of a car, and great attention is usually given to its use. Starting at the bonnet or dash, the swage is carried through the doors and around the back in one continuous sweep, thus forming the waistline of the car. It may take many forms, but a general design for saloon cars is a moulding of the form shown in Fig. 61 (*A*).

Arrowhead Moulding

On some coupé and sports models the moulding is made to separate at the rear, one part passing around the waist rail and the other following on to the tail. Another style of moulding in vogue is the arrowhead type, which starts at the dash as a narrow moulding about ¾ in. wide, widening as it follows an easy sweep to the back, and then terminating in a spearpoint (Fig. 61 (*B*)).

The moulding on a car is first "set" by the bodymaker, who makes a wooden moulding of the required shape and fixes it in the correct position. The panel beater makes his panel, and after smoothing in the wheeling machine, temporarily fixes it into position with panel-pins or cramps, and "marks off" the position of the moulding with a long bent scriber, the end of which rests on the wooden moulding which forms a guide while the scriber point marks out the exact shape and position on the panel as it is drawn along the moulding. If the moulding is parallel, the marking may be dispensed with and the guide on the swaging machine used in its place, but curved and tapered mouldings must be formed freehand, by guiding the panel through the swage wheels on the line marked off by the previously described

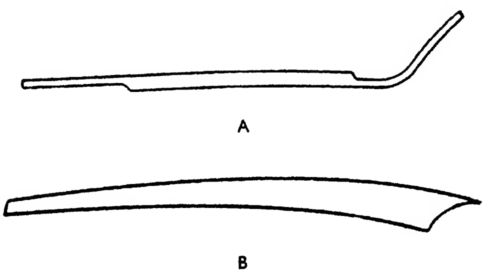


FIG. 61.—TYPICAL CAR-BODY SWAGES

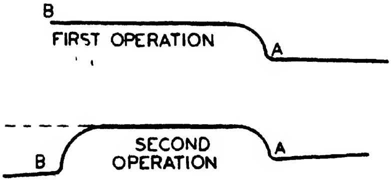


FIG. 62.—FORMING CURVED AND TAPERED MOULDINGS

method. For this work single-sided wheels are used (Fig. 63) so that the swage may be formed up, one side at a time (Fig. 62); or several wheels may be "ganged" together with suitable thickness packing washers between them to form a flat-topped moulding of any desired width (Fig. 64).

Swaging round Back Corners of Car Bodies

When swaging round the back corners of car bodies, the moulding has to stand out from the panel and therefore make a bigger sweep, which means that the outside of the moulding will be longer than the metal from which it was formed, and must therefore be stretched during operation. This stretching can be done with the wheels, but this is an undesirable method, as the wheels also pull the panel inwards at the points immediately below the swage. Although the resulting effect is not very unsightly, it is undesirable, as the panel is prevented from "seating" properly, thus causing it to fit incorrectly to the other panels. To avoid this the panel is stretched by beating it between a sandbag and studding hammer to give the necessary increase in area between the swage lines, and the wheels are then able to form up the moulding without disturbing the metal on either side of it (Fig. 65).

If the moulding is "swept," i.e. curved, but at the same time is parallel and the edge of the panel straight (as in the case of door panels), the swage guide may be used if a piece of scrap material cut out to the desired shape is fastened on with screws or rivets to act as a template. Thus, by pushing the panel so that the template is always in contact with the guide, a considerably cleaner contour is obtained than if the work was done freehand. When a swaged panel is mounted on the car the wooden moulding should fit inside the swage and, when all the swaged panels are assembled, should appear as a continuous moulding. Any breaks which may then be apparent are trued up by the use of hand chasers.

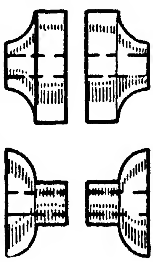


FIG. 63.—SINGLE-SIDED WHEELS FOR FORMING CURVED AND TAPERED MOULDINGS

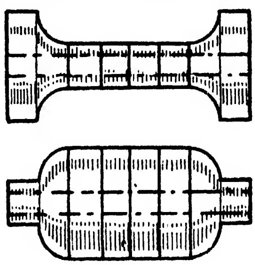


FIG. 64.—SINGLE-SIDED WHEELS GANGED TO FORM A WIDE PARALLEL MOULDING

Composite Swaging

Where a moulding is required of extra width or of more artistic shape than those formed by standard wheels,

it may be built up by using two or more pairs of wheels separately, some typical examples being illustrated in Fig. 66. Care must be exercised when making these swages to form them in such order that the wheels for one part of the swage do not foul the parts already formed.

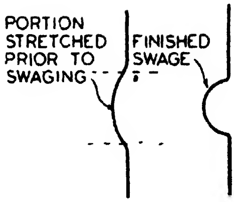


FIG. 65.—SWAGING ROUND BACK CORNERS OF CAR BODIES

Swaging Tubes and Pipes

Tubes and pipes that are to be joined by means of rubber hose and clips are swaged at their ends to make a watertight joint and to prevent the hose from pulling off. These pipes are usually too small to be swaged in the standard machine (as the wheel would have to fit inside the pipe), so it is necessary to use a tool known as a hand swage. This consists of a solid mandrel (with the shape of the swage turned on to the outside surface), and a top tool, similar to a grooving punch with a female impression, mounted over it in a slide or on a pivoted arm; the whole being mounted in a suitable frame (Fig. 67). The pipe is slipped over the mandrel, up to the stop, and the punch is tapped with a hammer whilst at the same time the pipe is rotated by hand, the whole device being usually held in a vice. The pipe is held vertically with the left hand while the punch is struck with a hammer, the pipe being rotated slowly until the swage has been completely formed.

Forming Moulding in a Cramp Folder

It may be required to form a wide moulding for which wheels are not available. Such mouldings may be formed, one bend at a time, by working from either side on a cramp folder, of which some typical examples are shown in Fig. 68. These sections are used for strength rather than appearance, and are often made separately and riveted to flat sheets to act as stiffeners or runner.

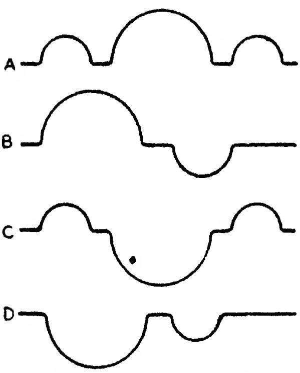


FIG. 66.—COMPOSITE SWAGING

Sometimes it is necessary to swage very large work, or work whose difficult shape prevents the use of standard machines, owing to the limited clearance between the shafts. Such work includes motor wings of helmet section, which requires a considerable amount of clearance on either side as it passes through the rollers. This difficulty can be overcome by replacing the normal wheels on a wheeling machine with swaging wheels (which usually have to be made specially) and rotating the shaft by means of the handle, which, for this purpose, is fixed to the end of the shafting projecting outside the frame (see section dealing with "Wheeling Machines").

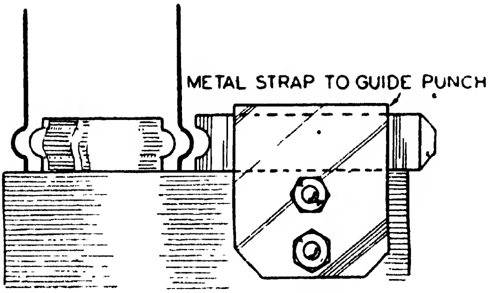


FIG. 67.—HAND SWAGE FOR PIPES

A guide cannot be used for this method, and the swage must be made freehand by working to a line, two operators being necessary to turn the handle and guide the work through the wheels. Due to the fact that the bottom wheel is supported on a pillar, there is almost unlimited clearance on either side, and despite the fact that only the top wheel is driven, a very satisfactory swage can be obtained.

Guttering

Guttering is made on a guttering press, which is an adaptation of the right-angle bending machine, fitted with a top and bottom tool to give the required section when the tools come together, in a similar manner to an ordinary press. Moulding and guttering tools are frequently made to be interchangeable with the tools used for right-angle bending, to enable their use on this standard machine.

Drawn Sections

Moulding, in long lengths as used for shop fronts, etc., and the stiffening sections (Z shape) used for "stringers" and "stiffeners" in aircraft work, are produced on a draw-bench, which usually takes the form of two channel or girder sections mounted parallel to each other, so that a slot is formed between them. A head is fixed at one end to hold the dies or swage wheels, and a travelling cramp or vice, operated through a geared handwheel and endless chain, travels along the whole length of the bed.

The raw material consists of a strip or ribbon of metal which is threaded through the two halves of the forming die, and locked in the travelling cramp, which then draws the metal through the die, thus forming it to shape. The two halves of the die are adjustable and slightly tapered to give a "lead" to the metal by roughly forming it to shape. It may be necessary to pass the material several times through the dies, starting with them slightly separated and then closing them a little for each successive run until they form the full shape. A heavy

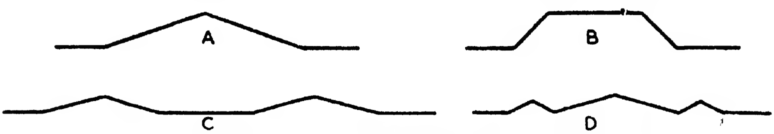


FIG. 68.—EXAMPLES OF MOULDING PRODUCED IN A CRAMP FOLDER

lubricant, such as beeswax or soap, is necessary when using this type of die in order to reduce friction and prevent damage to the surface of the work.

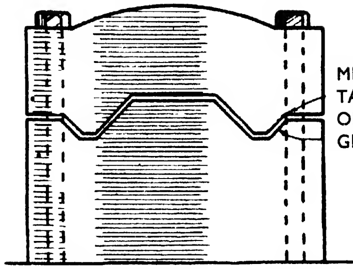


FIG. 69.—DIE FOR FORMING AIRCRAFT CHANNEL SECTIONS ON A DRAW-BENCH

A better method of producing moulding on a draw-bench, if the quantity is large enough to warrant the expense, is to use a series of swage wheels mounted as a battery, each successive pair of wheels forming deeper than those preceding until, finally, the full section is obtained. By this method sections may be obtained in one "draw," although, of course, a single pair of wheels may be used, as in a swaging machine, by taking the metal through them several times, adjusting the wheels closer after each "draw" until the full depth is obtained. Sections formed on a draw-bench have a tendency to distort and twist, owing to the edges becoming stretched in the forming process. These may be straightened by fastening each end and exerting a pull which will tend to stretch the centre and so take up the slack material in the edges.

JOINING SHEET-METAL WORK

Joints and seams used in sheet-metal work may be classified as either mechanical joints (where the edges of the metal are bent to a self-locking form), riveted, or metallic joints (soldering, brazing, and welding).

Grooved Joint

The most generally used form of mechanical joint is the grooved joint, which is made by folding the edges to be joined in opposite directions so that they hook together, then with a grooving punch (or "groover") the metal is set down to form the joint (Fig. 70). The groover has a half-round groove cut in its face, and when in use one side is held in contact with the open side of the seam, which acts as a guide, while the other side is set with light taps on the groover, at the same time as it is moved slowly along the seam. This should be repeated two or three times until the joint is flush on the inside. This joint is used extensively for tin work of all kinds, petrol tanks, cylinders, etc. When the joint is required to be flush on the outside, a sunk grooved joint is used, which is made by sinking the joint into a slot, such as a keyway in a shaft, or other suitable tool (Fig. 71).

Strip-seam Joint

Where the metal is too thin or thick or otherwise unsuitable for grooving (e.g. perforated gauze), a strip seam may be employed (Fig. 74), where the edges are folded and the strip introduced from the end.

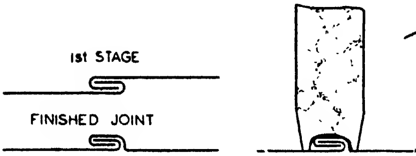


FIG. 70.—MAKING GROOVED JOINT
Right—showing how joint is accommodated in the grooves.

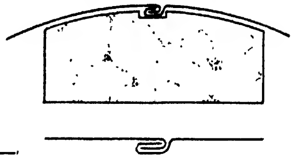


FIG. 71.—SUNK GROOVED JOINT
Bar with keyway for making grooved joints inside is shown at the top.

Box-corner Joint

For box corners, bottoms, or ends, the seam shown in Fig. 73 makes a neat and strong joint. This is made by turning a square edge on the end of one side and a fold on the other; these are engaged and then paned down and folded over, with a mallet or hammer, on a sharp-edged tool (e.g. the flat end of a mandrel).

Knocked-up Joint

Fig. 75 shows a similar joint employed for seaming bottoms, and is known as a "knocked-up joint." This is made by turning a flange out square with the body and turning an edge up square with the bottom, so that it is an easy fit over the flange. This edge is then gently paned down on to the flange and the whole edge knocked up, over a sharp-edged round tool (e.g. the round end of the mandrel).

In workshops where this type of joint is extensively used, simple machines are employed which turn the flanges (a Jenny is used for this operation) and form the joint with specially designed wheels on machines known as "paning-down machines" and "bottom-closing (or knocking-up) machines" respectively.

Riveted Joints

For riveted seams a lap of at least three times the diameter of the rivets is required. The seam is made by drilling a hole through the pieces just large enough to clear the rivet, which is inserted from the inside and slipped on to

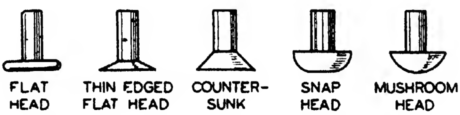


FIG. 72.—RIVETS

FIG. 74.—STRIP JOINT

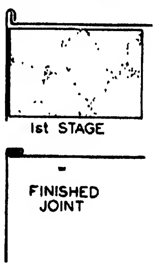


FIG. 73.—BOX-CORNER JOINT

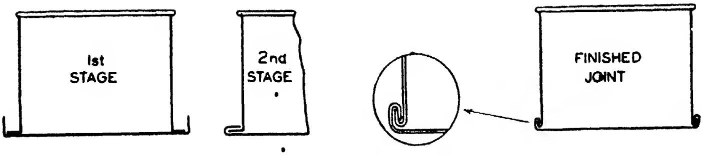


FIG. 75.—KNOCKED-UP BOTTOM JOINT

a suitable tool. A draw set is then used to "draw" the rivet through the hole. A few taps with a hammer will "spread" the top of the rivet, which is then "snapped up" by positioning the button set or snap over the rivet and giving one or two blows with a hammer. If the rivets are too long they should be cut down to about one and a half times the diameter of the rivet, which length should provide sufficient material to form a good snap head.

With snap-head rivets, a "dolly" is used under the rivet head, this being simply a suitable bar with a cup formed in it to fit the rivet head. Rivets are made with different-shaped heads and in various sizes (both length and diameter), and of metals to suit the material to be joined. Iron, copper, aluminium, Dural, brass, and stainless-steel rivets are made for use, and rivets of the same metal as those to be joined should be used. Where two dissimilar metals are to be joined, a compromise must be made; thus copper rivets are frequently used for both iron and brass, and aluminium rivets for jobs where a very soft rivet is required. Tubular rivets are sometimes used for light structures on aircraft, and are set by spreading the ends with a belling punch or other suitable tool.

Where a joint is under shear strain and the rivet pitch required would be too close, a double staggered row of rivets is used.

Riveting—Using Dolly

When riveting is to be carried out *in situ*, as for aircraft construction, tanks, etc., it is necessary to use a "dolly" behind the rivet, against which it is hammered up. For flat-head and countersunk rivets this may be any flat of steel or steel bar held endways against the rivet head, but for snap-head rivets a hemispherical depression must be made to accommodate the head and preserve the shape. This may be made by first drilling a "countersink" in the end of a suitable bar, heating to redness, and then using a punch and steel ball of the correct size, to complete the cup. For work entailing the use of a "dolly," two operators work together, often out of sight of each other. The man on the inside of the job puts the rivet into the hole and holds the dolly against the head and then signals his partner that he is ready; the rivet is then cut and snapped up in the usual way with a rivet set or pneumatic riveting gun, if the latter is available.

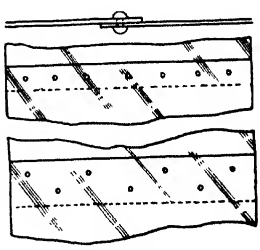


FIG. 76.—RIVETED SEAMS

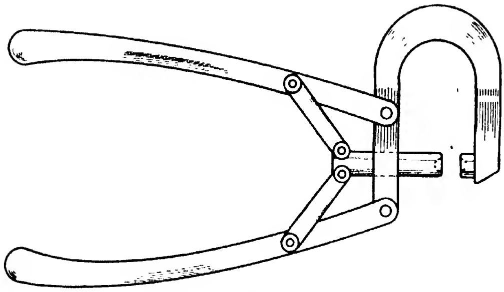


FIG. 77.—RIVET SQUEEZE

Rivet Squeeze

A very useful tool for riveting aluminium and Dural fittings is the rivet squeeze, a tool resembling a bear punch, but with rivet cups fitted in place of the punch and die. This makes a neat and quick job when closing soft rivets, but its capacity is limited to the depth of the throat, which is usually 3–4 in.

Flush Finish

Riveted work on which a flush finish is required is obtained by using countersunk-head rivets, if the metal is thick enough to take the countersink, or on thin metal with flat-head rivets, using a recessed draw punch, the metal being drawn into a cup to accommodate the head without weakening it. Where fittings are to be flush riveted to sheet metal, the best method is to countersink the fitting only, and use countersunk rivets. When drawn up in the usual way, the head will pull the sheet up into the countersink in the form of a conical cup, thus preserving its strength.

Tinned-steel tanks are usually riveted with tinned-copper rivets and the joints and fittings sealed by "sweating" after riveting. Dural, of course, cannot be soldered, but is sealed by inserting jointing material between the laps before riveting.

SOLDER AND SOLDERING

The process of soldering is an amalgamation between two metals, the solder and the work, and it naturally follows that the surface of the work should be clean, as the solder will adhere only to metal, and not to a film of dirt, grease, or rust which may cover the metal. Soft solders are alloys of lead and tin in approximately the following proportions:

TABLE II.—SOFT SOLDERS

Type	*Lead*	*Tin*	*Bismuth*
Plumber's solder . . .	3	1	—
Tinman's (general purpose) .	1	1	—
Tinman's (fine) . . .	1	2	—
Pewterer's solder . . .	1	1	2

Bismuth solder, which is used for pewter and other alloys having low-melting temperatures, has a melting-point of only 203° F., less than the boiling-point of water.

Soldering Fluxes

When soldering, a flux is used to break down and float off oxide and other surface impurities and to prevent the formation of oxide by the heat. The most generally used flux is "killed spirits," made by dissolving as much zinc as possible in muriatic acid or spirits of salts (i.e. a saturated solution). This should be done in a wide-necked earthenware jar, in the open air. The jar should not be more than half-full, as the violent chemical action causes it to "boil up." When "killed" there should be some undissolved zinc still left at the bottom, and the liquid should be clear and colourless. This is used as a flux for copper, brass, iron, and tinplate.

Raw spirits of salts is used as a flux for zinc and galvanised iron.

Sal ammoniac is used when tinning iron, copper, brass, and cast iron, this being a very powerful flux, but is highly corrosive and must be thoroughly washed off after use.

Tallow is used as a flux for lead and plumbers' wiped joints, and resin is used as a flux for lead and electrical work where an acid flux must be avoided. Mixed together, tallow and resin make a useful paste flux.

Making a Soldered Joint

For an ordinary soldered joint, a lap joint of $\frac{1}{8}$–$\frac{3}{8}$ in., according to the thickness of the metal, is required. The joint is then fluxed and solder applied with a hot, well-tinned copper bit, with its edge in contact with the work.

As the copper bit is only a convenient reservoir of heat, it should be left in contact long enough to warm the work up to the melting temperature of the solder, which will then be seen to spread over the surface of the metal. The bit should then be drawn along the joint, using the edge of the top lap as a guide, and fed with solder on the top face, from where it will run down into the joint. The solder will follow the copper bit, so it must not be allowed to wander off the joint or an unsightly smudge will be produced. The solder is fed on to the iron by dabbing the face from time to time with the stick of solder.

When the edge of the solder on the joint forms up into a ridge it is an indication that the bit is becoming too cool for further work and should be re-heated.

If, after heating, the bit "smokes," it is too hot for use and should be allowed to cool slightly, so that when dipped into flux the tinned faces remain bright. When a copper bit has been overheated so that the faces are burnt black, it must be cleaned up with a file, preferably while hot, and re-tinned by dipping into flux, applying solder, and rubbing on a piece of tinned metal.

As solder has very little mechanical strength, a soldered butt joint is unsatisfactory, due to the fact that the solder would have only the thickness of

the metal to which to adhere. If a flush joint is required, a strip of metal should be "sweated" on from the back, this being known as a strap joint.

Sweated Joints

A "sweated" joint is a joint which is soldered through the whole surface of the two pieces in contact. Sheet-metal joints are usually "sweated" by applying the copper bit flat, on top of the joint, so that it is heated completely through, and solder will be seen to "sweat" out from the other side, thus indicating that the solder has penetrated right through the joint, soldering together the whole of the two surfaces in contact. Tank rivets may be neatly "sweated" from the outside by holding one face of the bit in contact with the rivet head only, and allowing the solder to flow down and around it, giving a perfect seal and confining the solder to the vicinity of the rivet head, in a small neat ring.

In cases where the heat stored in a copper bit is inadequate, the surfaces which are to be sweated together are first "tinned" by coating with solder, then, after positioning the two pieces, heat is applied with a blowpipe until the surplus solder is seen to exude from the sides of the joint when pressed together. This joint, if not otherwise held in position, should be kept tightly pressed together until the solder sets.

Floating and Bridging

Floating and bridging are two methods of soldering which are very useful on certain classes of repair work, but it must be emphasised that these methods are not used for any aircraft work, as they come more in the category of "faking" than of jointing. A hole which is to be filled with solder may be "floated" by laying the bit over the hole with its whole face in contact, and at the same time drawing it sideways, with both sides of the hole in contact with the face of the bit. The solder will spread in the form of a film across the hole and join up with the other side. Small holes may be filled by inserting the point of the bit into the hole, twisting it around and withdrawing vertically. "Bridging" a gap with solder is done by building up with solder from both sides, using a cool bit, until it joins. This can rarely be done neatly, and it is usually filed or scraped afterwards.

Silver-soldering

Silver-solder is an alloy of copper, zinc, and silver, used mainly for joining brass and copper, borax being used as a flux, and the process produces a neat, strong joint. As the solder is fairly strong in itself, material of a suitable thickness may be butt joined, but in most cases sheet-metal joints are scarfed and lapped to give a larger area of contact. A scarfed joint is made by thinning the metal on one side to produce an acute angle, so that when the two scarfed edges are lapped, the total thickness is that of the single sheet. When two pieces are to be joined at an angle they may be propped into position and silver-soldered, the solder forming a fillet which will be of ample strength for most jobs.

To silver-solder a joint it is necessary to first lay the parts in position, and,

if required, fasten the parts with fine binding wire, clamps, or weights. The flux, which is made by mixing borax and water to the thickness of cream, is next painted sparingly on to the work (this should be confined to the joint, as surplus flux is difficult to remove after it has been fused) and the joint heated with a blowpipe, or other convenient source of heat, until the flux fuses and runs into the joint. Next warm up the end of the silver-solder and dip into flux. Continue heating the joint, stroking it from time to time with the end of the silver-solder until it is hot enough to melt off a little from the end, which will follow the flux and run into the joint.

Silver-solder should be used sparingly both in the interests of neatness and economy, as it is fairly expensive. If necessary, more flux may be added and the flow assisted by using a spatula made by flattening the end of a piece of wire with a hammer. After cooling, the flux (which is now like glass) must be removed by chipping or filing and the joint cleaned up.

Silver-solder is usually supplied in the form of ribbon, which is then cut into thin strips and mounted in a suitable holder to eliminate waste.

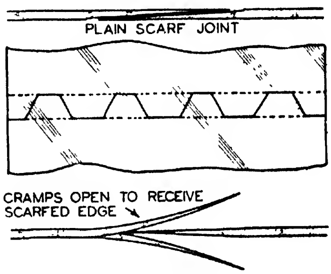


Fig. 78.—Cramped joint for brazing

Brazing

The process of brazing is similar to silver-soldering, except that brazing wire is used for joining material and a rather higher temperature is required. This is used for joining copper and steel. Brazing spelter is sometimes used in place of brazing wire, this being a mixture of granulated brass and borax, which is sprinkled on the joint, and then heated until the spelter fuses. Where an extra strong joint is required, the edges to be joined are scarfed and a series of cuts made in one edge, dovetail fashion. These cramps are then bent alternately up and down, the plain scarfed edge inserted, and the whole joint hammered up tight. This is then loosened a little by tapping the end of the joint edgewise with a hammer, so that the brass may flow between the cramps and the scarfed edge.

WELDING

Welding, both oxy-acetylene and electric spot welding, is playing an increasingly important part in the fabrication of sheet-metal work.

Oxy-acetylene Welding

Fusion welding with an oxy-acetylene flame is a process by which the edges of the pieces to be joined are melted and run together, fresh metal being added, to make up losses and gaps, by means of a filler rod of the same composition as the metal to be welded. The oxy-acetylene fusion welding process is described in the article beginning on page 56.

TABLE III.—GAUGES, THICKNESS, AND WEIGHT OF BLACK SHEET IRON AND STEEL

(Gauge measured in Birmingham Wire Gauge)

Gauge No. B.W.G.	*Thickness in Inches*	*Weight per Sheet 72 in. by 24 in.*		*Weight per Sheet 72 in. by 30 in.*		*Weight per Sheet 72 in. by 36 in.*		*Weight per Square Foot*	
		qr.	lb.	qr.	lb.	qr.	lb.	lb.	oz.
10	0·125	2	14	3	4	3	21	5⅝	0
11	0·111	2	4	2	19	3	6	5	0
12	0·099	1	26	2	12	2	25	4½	0
13	0·088	1	20	2	4	2	16	4	0
14	0·078	1	13	1	23	2	5	3⅜	0
15	0·069	1	8	1	17	1	26	3	0
16	0·062	1	2	1	10	1	17	2½	0
17	0·055	0	27	1	6	1	13	2¼	0
18	0·049	0	24	1	2	1	8	2	0
19	0·044	0	21	0	26	1	3	1¾	0
20	0·039	0	18	0	23	0	27	1½	0
21	0·034	0	16	0	21	0	25	1⅜	0
22	0·031	0	15	0	19	0	23	1¼	0
23	0·027	0	14	0	17	0	20	1⅛	0
24	0·024	0	12	0	15	0	18	1	0
25	0·022	0	11	0	13	0	16	0	14
26	0·019	0	10	0	12	0	14	0	13
27	0·017	0	8	0	10	0	12	0	10¾
28	0·015	0	7	0	9	0	10¾	0	9½
29	0·013	0	6	0	7½	0	9¼	0	8¼
30	0·012	0	5½	0	6½	0	8½	0	7½

TABLE IV.—IMPERIAL STANDARD WIRE GAUGE

Standard Wire Gauge	*Equivalent in Inches*	*Standard Wire Gauge*	*Equivalent in Inches*	*Standard Wire Gauge*	*Equivalent in Inches*
1	0·300	13	0·092	25	0·020
2	0·276	14	0·080	26	0·018
3	0·252	15	0·072	27	0·0164
4	0·232	16	0·064	28	0·0148
5	0·212	17	0·056	29	0·0136
6	0·192	18	0·048	30	0·0124
7	0·176	19	0·040	31	0·0116
8	0·160	20	0·036	32	0·0108
9	0·144	21	0·032	33	0·0100
10	0·128	22	0·028	34	0·0092
11	0·116	23	0·024	35	0·0084
12	0·104	24	0·022	36	0·0076

TABLE V.—TINPLATE SIZES, GAUGES (B.W.G.), AND MARKS

Mark on Sheet	*Nearest Gauge (B.W.G.)*	*Thickness in Inches*	*Size of Sheets*
1 C	30	0·012	20 in. by 14 in. and 28 in. by 20 in.
1 X	28	0·014	
1 XX	27	0·016	
1 XXX	26	0·018	
1 XXXX	25	0·020	
1 XXXXX	24	0·022	
1 XXXXXX	22, slack	0·027	
DC	28, full	0·015	17 in. by 12½ in. 25 in. by 17 in. 25 in. by 34 in.
DX	26	0·018	
DXX	25	0·020	
DXXX	24	0·022	
DXXXX	22	0·028	
DXXXXX	21	0·032	
DXXXXXX	20	0·035	
SDC	28, full	0·015	15 in. by 11 in. and 15 in. by 22 in.
SDX	26	0·018	
SDXX	25	0·020	
SDXXX	24	0·022	
SDXXXX	24, full	0·023	
SDXXXXX	23	0·025	
SDXXXXXX	22, full	0·029	

TABLE VI.- COPPER SHEET (4 ft. by 2 ft.)

(Copper sheets are usually manufactured in one size only, 4 ft. by 2 ft., the thickness not being classified in gauge numbers, but by the weight of the sheet (in lb.). Thus a sheet of copper which is 20 B.W.G. thick is known as "14 lb. copper," this being the weight of a full sheet of this thickness.)

Lb. per Sheet	*Nearest B.W.G.*	*Lb. per Sheet*	*Nearest B.W.G.*	*Lb. per Sheet*	*Nearest B.W.G.*
4	30	12	21	28	15
5	28	14	20	32	14
6	27	16	19	36	13
7	25	18	18	40	12
8	24	22	17	44	11
9	23, slack	24	16	50	10
10	22, slack				

Spot Welding

Spot welding is an electric process where a heavy low-voltage current is applied to two electrodes, which are brought together with considerable mechanical pressure. The metal offers a higher resistance to the current than the

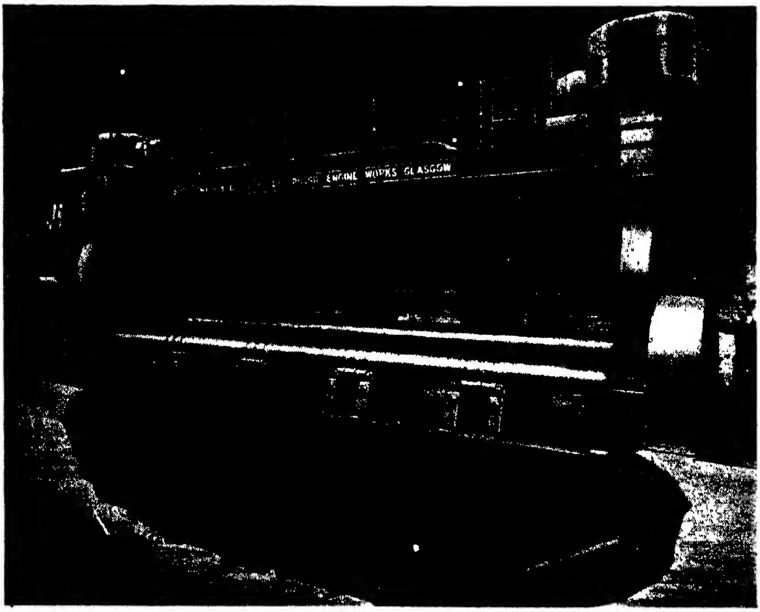


FIG. 79.—40-FT. × 2-IN. MILD-STEEL PLATE BENDING ROLLS (*Hugh Smith & Co.* (*Possil*), *Ltd.*)

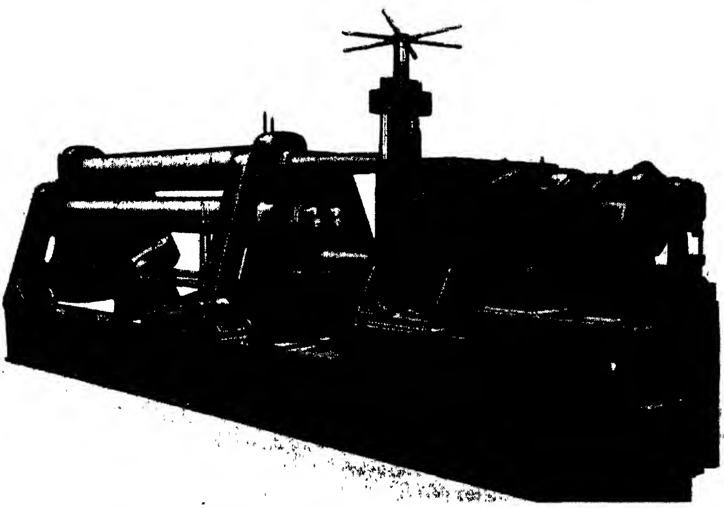


FIG. 80.—COMBINED PLATE BENDING AND STRAIGHTENING ROLLS
(*Hugh Smith & Co.* (*Possil*), *Ltd.*)

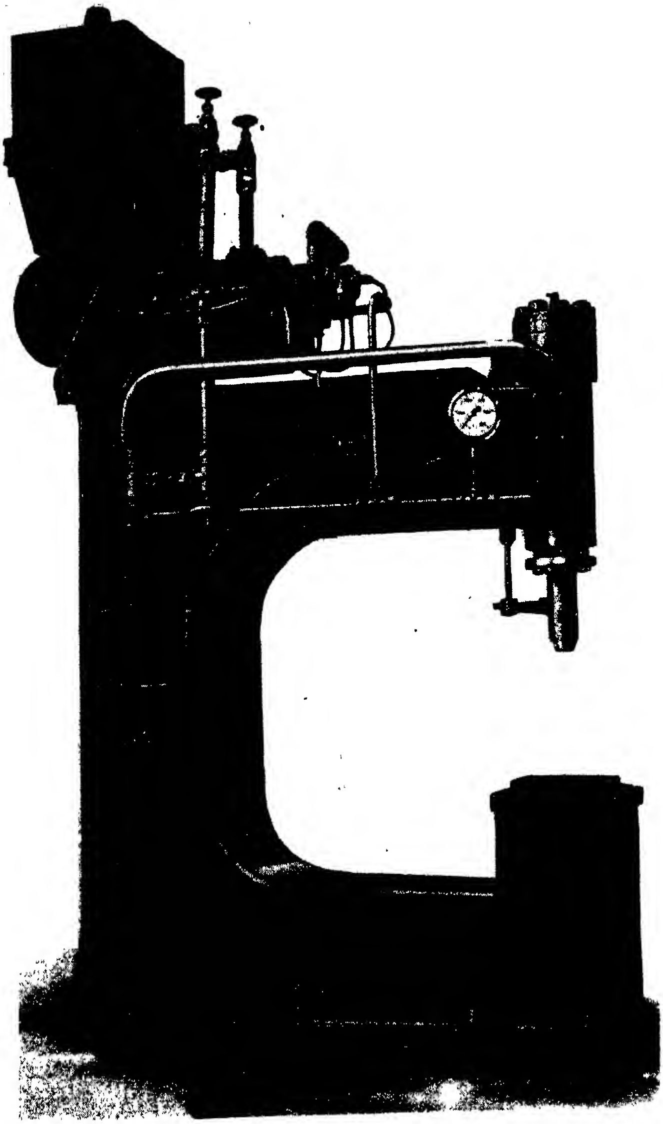


FIG. 81.—25-TON HYDRAULIC VENTILATOR DISHING PRESS
(Hugh Smith & Co. (Possil), Ltd.)

electrodes, and rapidly becomes hot enough to be plastic, at which moment the mechanical pressure completes the weld on the spot between the electrodes. Each spot takes only a second or so to make and the effect is that of a rivet. Resistance welding is most effective on sheet iron and steel, but machines are now built to weld aluminium and other non-ferrous metals. Special types have been developed for butt and seam welding for use on motor panels, tanks, etc.

In operation, it is only necessary to hold the two parts in position and feed them between the electrodes, closing them by pressure on a foot pedal. Due to the fact that the heat is very localised, there is an absence of distortion, and the work can be comfortably held in the hand during the process (see p. 34).

PLATE-BENDING EQUIPMENT

The above article refers only to comparatively light-gauge metal, and for the manipulation of steel plates, various types of power-driven equipment have been devised.

Fig. 79 shows a machine for bending plates up to 40 ft. long, in maximum thicknesses of 2 in. for mild steel and 1½ in. for Admiralty "D" quality. The clear length between end housings is 41 ft., and the machine is suitable for cold bending the plates of the heavier naval and merchant ships.

The four-roller combined bending and straightening rolls shown in Fig. 80 is a useful machine where the amount of plate work to be done does not justify a separate machine for each duty. Complete circle work of the same range as a single-purpose machine can be performed, but the straightening performance is not so good as a seven-roller straightening machine.

Fig. 81 shows a fabricated 25-ton hydraulic dishing press for dishing sheet metal components, such as ventilator cowls or any articles requiring similar treatment. It has a self-contained electro-hydraulic pump, and operates up to a maximum speed of 25 strokes per minute, the return stroke being twice as fast as the working stroke.

BENDING BY MACHINE

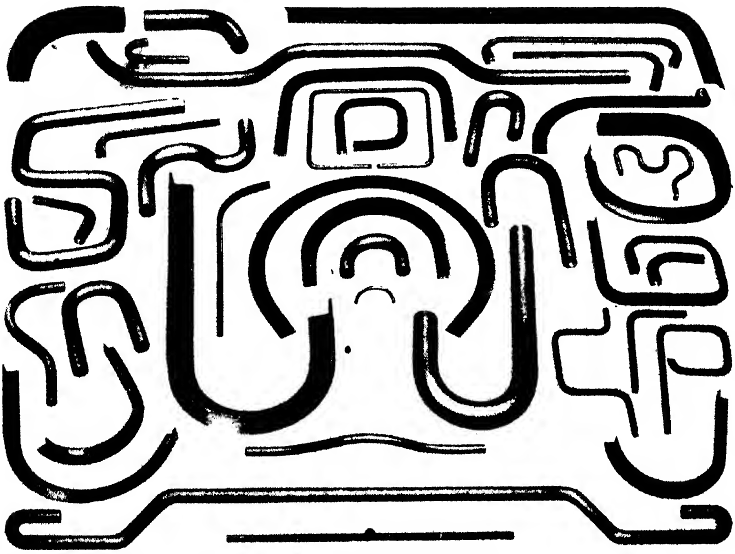


FIG. 1.—GROUP OF TYPICAL BENDS PRODUCED BY MACHINE

THE work of the skilled bending-machine operator is as important in its sphere as that of an experienced turner. Bent tubes have to be made in a great variety of sizes for use in almost every industry. They are used in many types of machines, including transformers, refrigerators, geysers, superheaters, and for conveying electric cables, water, gas, steam, petrol, and oil.

The setting up of a bending machine for any particular work calls for great skill and craftsmanship, and an experienced bending operator has every reason to be proud of his machine and the work it produces.

New tubular sections in all metals, with various applications, are appearing in different trades almost daily. Most of them require to be bent to form a certain shape or component, and an experienced operator has to know what type of machine to use, and all the different methods of bending that are available.

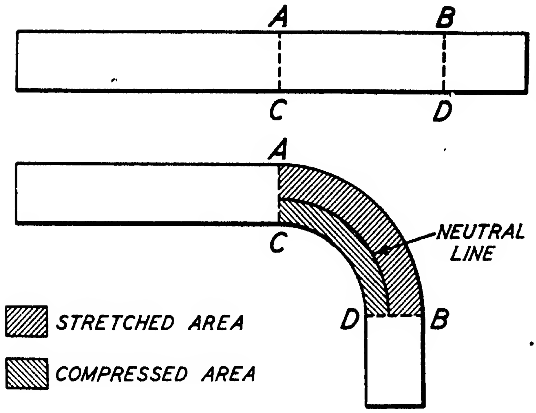


FIG. 2.—AREAS OF STRETCH AND COMPRESSION WHICH OCCUR WHEN A FLAT BAR IS BENT

Different sections require different types of formers. For instance, iron pipes do not need such an exact protection as that required by light-gauge tubes, and it is to give information on such points as these and many other important considerations that this article has been written.

Structural Alteration of Metals by Bending

Whenever any bend is made—that is, whenever a tube or any other section is turned from a straight course to an altered path—the structure of the metal undergoes a certain change, because the inner and outer sides of the material are compressed and stretched respectively.

If a piece of tube or section is, say, 12 in. long in the straight, it will, after bending, be longer on the outer side, or heel, of the bend, and shorter on the inner side, or throat, than the original length.

Fig. 2 shows a piece of flat material before and after bending. The outer side of the bend *AB* has been stretched while *CD* has been compressed. It follows, therefore, that the outer half of the bend has to cover a larger area than the same portion did in the straight. This increase in area, due to stretching, is gained at the expense of the thickness, which is lessened. Exactly the opposite occurs on the inside of the bend, which occupies a smaller area than when in the straight; there is here too much metal to occupy the area, and the surplus is disposed of by a thickening up of the inner part of the bend. The amount of structural alteration depends on the radius of the bend and the width of the material to be bent.

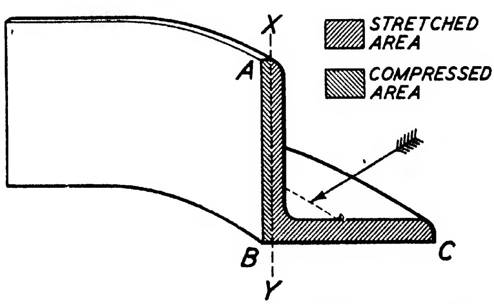


FIG. 3.—AREAS OF STRETCH AND COMPRESSION WHICH OCCUR IN BENDING AN ANGLE SECTION WITH THE WEB ON THE OUTSIDE OF THE BEND

From the fact that one side of the bend is stretched, and that the other is compressed, it

follows that there must be a neutral line where no structural alteration takes place, and that the farther away from this neutral line, the more extreme the stretch and compression.

It will be seen that the neutral line shown on the flat section in Fig. 2 is not exactly in the centre, but is nearer the inside of the bend. This is explained by the fact that more force is required to compress the metal than to stretch it, and therefore there is in this particular section slightly more stretch than compression, and the neutral line is therefore nearer the throat of the bend. In all equal sections the neutral line is found in this position.

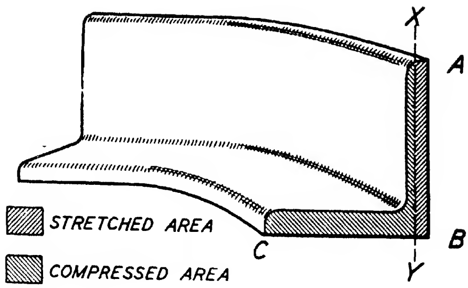


FIG. 4.—AREAS OF STRETCH AND COMPRESSION WHICH OCCUR IN BENDING AN ANGLE SECTION WITH THE WEB ON THE INSIDE OF THE BEND

When bending an irregular or unequal section, the position of this line is altered, and depends on the direction of bend. For instance, angle section when bent with the horizontal web on the outside has a very small portion of the bend in compression. If the shaded portion *BC* (Fig. 3) only was being bent (i.e. a piece of flat as in Fig. 2), the neutral line would be in position indicated by the arrow, as previously explained; but there is now the addition of the vertical web which comes in contact with a circular former round which the bend is made, and which is strong enough to resist compression, with the result that the neutral line is approximately at *XY* on the vertical web. Thus it will be seen that practically the whole of web *BC* stretches.

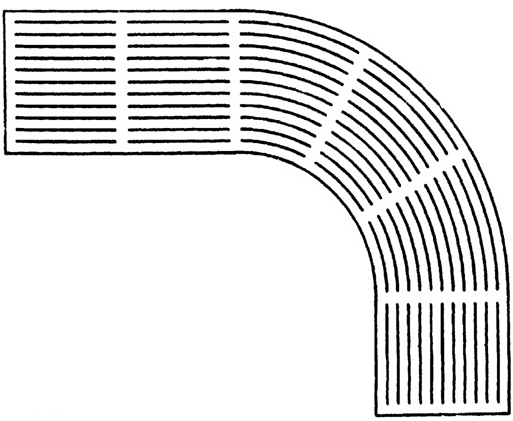


FIG. 5.—UNIFORMITY OF STRUCTURAL ALTERATION IN A FLAT BAR BENT ON EDGE

When the angle is bent with the horizontal web on the inside (Fig. 4), it is the stretching that is resisted by the vertical web, and the angle comes in contact with

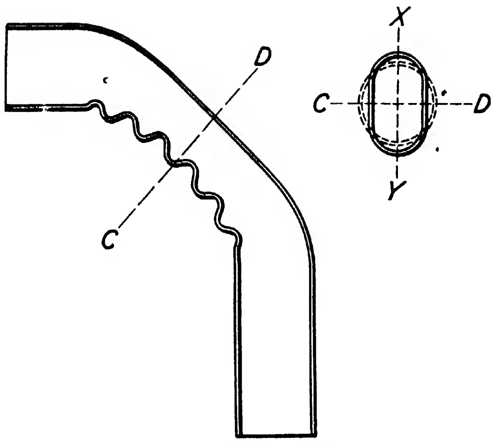


FIG. 6.—DISTORTION TENDENCIES ON A TUBE WHEN BENT WITHOUT SUITABLE PROTECTION (EXAGGERATED FOR CLEARNESS)

the former against the inside of the vertical web *AB*, with the result that the whole of web *CB* on the inner side of the neutral line *XY* is compressed.

Thus it will be seen that the neutral line is to be found slightly out of centre (and towards the inside of the bend, on the regular part of the section that comes in contact with the bending former.

It will now be understood that, theoretically, there can be no such thing as a perfect bend. Even if the bore has been maintained, the walls of a tube cannot retain their original thickness, because stretch and compression must take place in bending. In some sections a blacksmith can displace the metal when hot, so that the true section is formed on the bend, but this does not affect our remarks, as it is really an extra process after bending.

The fact that in theory there is no perfect bend does not prevent bends being absolutely perfect for the job to which they are applied. The degree of accuracy required depends on the use to which the bend will be put. Tubes and sections bent to form aircraft components must be made to conform with the strict limits imposed by the A.I.D. "Show" bends, such as hand rails, steel furniture, and motor-cycle exhaust pipes, etc., must appear neat and perfect to the eye, in section, and arrangement of bends; there is in such instances only the tolerance allowed by the limitations of the human eye. Hidden bends, such as those in conduit beneath floors, obviously need not be so neatly arranged, polished, nor have such an exact bend, so long as the bend is efficient for the job. Conduit bends must have the bore maintained to allow the wiring to be passed through the tube.

Thus, the tolerance allowed in bending differs with the class of work being done, and the ultimate use to which the bend will be put.

Mechanical Bending Methods

It is not proposed to deal with hot bending in this article, as it is not considered good workshop practice except for occasional jobs, and when bending is done hot, it is generally processed in this way to produce a forging where a certain "upsetting" is required.

The four general mechanical methods of bending are:

1. Press bending.
2. Roll bending.
3. Revolving former bending or draw bending.
4. Stationary former bending or compression bending.

Press Bending

In this method the work is held by two supports which are free to rotate (Fig. 7). The bend is made by a ram with a suitable former head forcing the work between the two supports and to conform to the shape of the former. This type of bender is usually hydraulically operated.

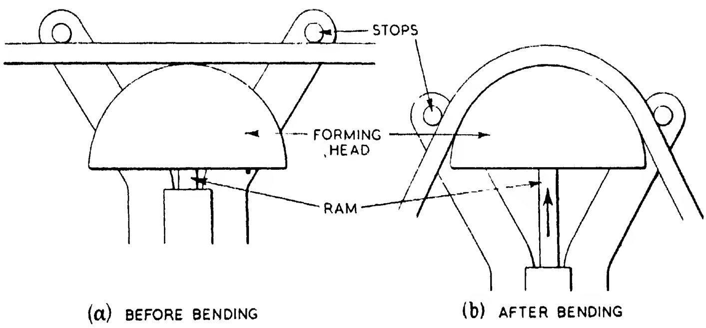


FIG 7.—RAM OR PRESS METHOD OF BENDING

The advantage of this method is portability of the bender, but the limitations are:

(*a*) Light-gauge tubes and sections cannot be bent, because the protection given to the work to prevent distortion is so slight.

(*b*) Bends cannot be made close to one another.

(*c*) A comparatively large radius is needed.

(*d*) It is unsuitable for bending sections, except for the simplest flat and round bars.

Roll Bending (Fig. 8)

In this method the work is passed through three rollers, the centre roller providing the adjustment controlling the radius of bend.

The protection of the section is limited, and this method is usually adopted for large radius bending. Coiling may be done, provided the radius is large enough for the work to spring over to its own thickness without acquiring a permanent set. Thus this method is very useful for complete large circles.

Revolving Former Bending

This is known also as draw bending. The work is clamped to a suitable former, and this when rotated draws the work past a shoe or roller, which forces it to conform to the radius of the former (Fig. 9).

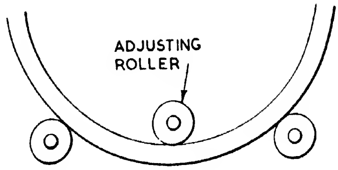


FIG. 8.—METHOD OF ROLL BENDING

Owing to the drawing action, the work is stretched to a greater degree than by other methods, and for bending the tube an inside mandrel or bar is used to support the tube internally.

The tube can therefore be protected on the outside by the shape of the former and shoe, and internally by the drawbar. The drawbar can be advanced beyond the bending point and performs the following functions:

(*a*) The maintenance of the true section just behind the bending point.

(*b*) The advance beyond the bending point prevents the outside of the bend from falling inwards.

(*c*) The drawbar exerts a certain ironing effect, preventing inside ripples.

Thus, sharper unloaded bends can be made than by any other method, but the tools required are more elaborate and expensive.

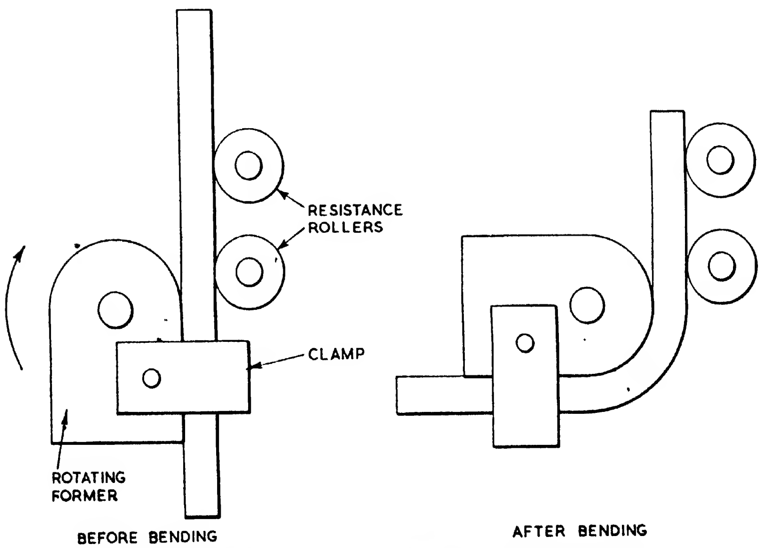


FIG. 9.—METHOD OF ROTATING FORMER OR DRAW BENDING

Stationary Former Bending

This is also known as compression bending, and is certainly the most widely used method of bending. The work is pushed or wrapped round a stationary former of the required shape and radius by a roller, or roller and back former.

The machines described in the following pages are mostly of this type.

"Kennedy" bending machines are designed to make bends quickly in a large variety of tubes and sections in light- and heavy-gauge metals, and to give protection and support during the bending to prevent distortion of the tube. There is no need for loading, no undue effort in bending, and no need for hours of dressing up and subsequent unloading. A bend which, by the old

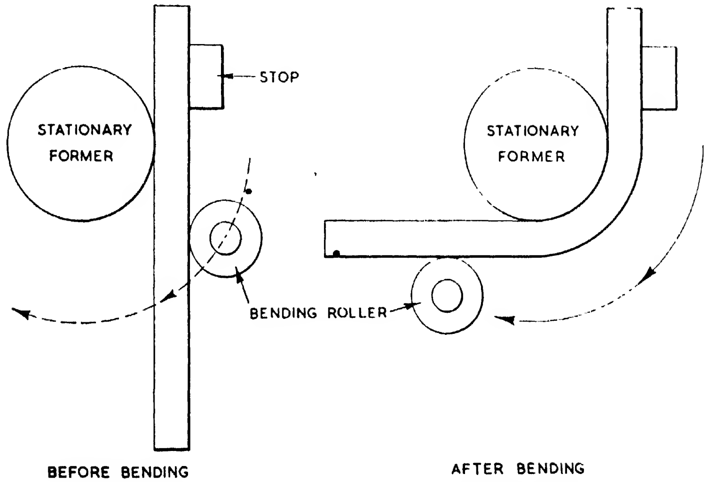


FIG. 10.—METHOD OF STATIONARY FORMER OR COMPRESSION BENDING

hand method, took perhaps an hour to produce, can be bent by machine in a few seconds.

It is not suggested that there is no skill now required in bending. There is still scope, and much more scope for craftsmanship, but the stage where skill is required has advanced. An unskilled man can with a machine make a bend that previously required highly skilled labour, but a skilled bending machine operator, with the help of his machine, can make bends that were previously impossible.

The illustration shown in Fig. 11 is of the smallest "Kennedy" machine made, but it incorporates all the features of the larger machines, and the principle is the same in all sizes. The roller and spindle (which in the larger machines is mounted upon a wormwheel and revolved by means of a worm and pilot wheel) is carried by the bending head and moved by a lever.

An adjustable top plate fits the screwed mandrel of the body. This plate prevents the tube or section distorting when being bent round the former.

A stop holds the work while bending is in progress. The tendency of the work to expand or distort when being bent is prevented by the top plate, which is thus tightened, and it is necessary to provide means of releasing it when the bend has been made; a plunger fits into any of the four holes in the top plate, which can then be unscrewed by means of the lever. In the larger machines a short tommy bar is provided to fit horizontally into holes in the top plate, and the roller stud brought into contact with it to unscrew the top plate.

The profile of the former round which the bend is made depends upon the shape and size of the sections to be bent.

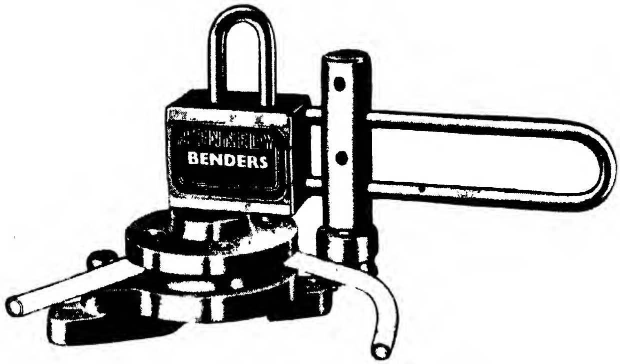


FIG. 11.—SMALL UNIVERSAL BENDING MACHINE

COLD BENDING *v.* HOT BENDING

Many people used to be under the impression that bends should be made hot—not only because less force was required to shape it, but because it was considered detrimental to the material if it was bent cold.

The strength of a bend depends upon the uniformity of the structural alteration. Structural alteration, as explained before, must take place whether a bend is made hot or cold. There must be stretch and compression.

In cold bending the absolute minimum of alteration in the structure of the metal takes place because the alteration is uniform.

If we take a piece of, say, 2-in. × $\frac{1}{8}$-in. mild-steel flat bar with a raised regular pattern on it, i.e. a stair tread, and bend it by machine cold, it will appear as shown in Fig. 5, and it will be noted that the pattern is still perfectly regular and unspoiled. The raised bars of the pattern, which were all of equal length in the straight, have been stretched and compressed on the bend as already described; but the bars are absolutely regular, radiating from the centre radius. This indicates that each minute portion of metal has a definite amount of stretch or compression to accomplish, and no more. Now imagine this bend made hot.

In the first place, it is not easy to heat it to absolutely the same temperature all over, and directly it was handled by tongs or came in contact with a vice or anvil, the temperature would drop, so that the bar would not have an even temperature all over. Therefore, when the bending took place the hottest parts would stretch and compress more readily and to a greater degree than the cooler parts. This would be reflected in the pattern which, instead of being perfectly uniform, as in a cold bend, would be spoilt. Some of the ridges would be stretched and compressed too much, and others not enough. Added to this, of course, there would be kinking which, when hammered out, would leave unsightly marks marring the pattern. In short, it is impossible to make this bend hot and by hand without ruining the pattern, and ruination of the pattern is a sure sign of weakening in the section owing to undue and irregular stresses.

We will now consider the case of a bend in iron pipe. If an iron pipe is gripped in a vice, made red hot, and pulled, a bend is made; that is to say, it is a bend inasmuch as the pipe has been manipulated so that part of it has changed direction by having been moved through so many degrees of angle. This of course is a very crude way of bending and a pipe so bent would tend to resemble Fig. 6, which has been exaggerated for clearness.

It will be noted that:

1. No regular or predetermined radius is formed.

2. In the throat of the bend, where there is no protection, the surplus metal has puckered, instead of uniformly thickening the wall of the pipe.

3. The outside wall caves in, taking the line of resistance, which is a short cut between *A* and *B*. This reduces axis *CD* and increases axis *XY*, thus reducing the bore of the pipe.

A skilled man can, of course, make a large-radius bend hot quite satisfactorily, but it requires skill and time, not to mention the inconvenience of heating the pipe.

On steam pipes or pipes of thicker gauge, the unwelcome tendencies mentioned are counteracted on the bending machine by the following means:

1. The pipe is bent cold round a positive former of the required radius.

2. The former is grooved to fit the tube; the thickness of the former, it will be noted, is slightly less than the outside diameter of the pipe, so that the top plate can be screwed down to grip the pipe without touching the former. This leaves a space between the top and bottom plates which is the exact width of the pipe. Thus it is impossible for the pipe to increase on axis *AB* while bending, and the fact that the diameter on this axis cannot increase prevents the outer wall from making such a short cut as shown in Fig. 6.

The bend is made by pressure of a grooved roller which is moved radially round the former, and this appears, so far as the eye can see, perfect. Actually the pipe has decreased slightly on axis *CD*. The axis *AB* remains the same as originally, the throat has not puckered but has thickened up, and the outer wall, or heel, is slightly thinner.

With regard to sections other than pipes, such as light-gauge tubes, angles,

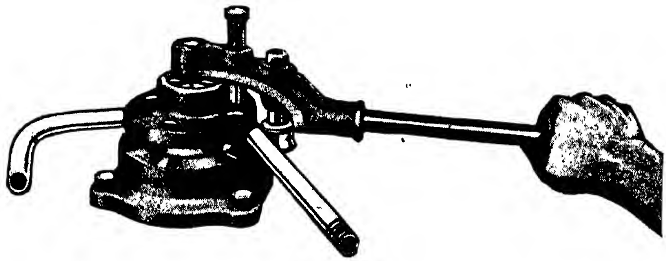


FIG. 12.—UNIVERSAL BENDER FOR PIPES UP TO ½-IN. BORE

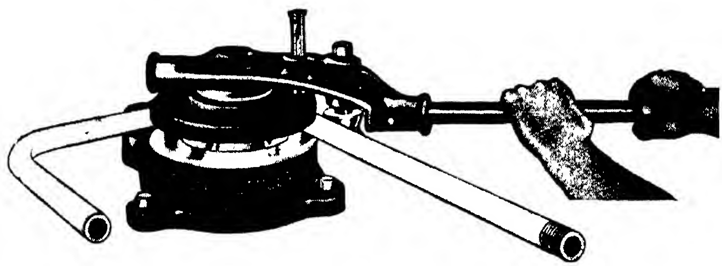


FIG. 13.—BENDING A 1-IN. STEAM PIPE USING A UNIVERSAL BENDER

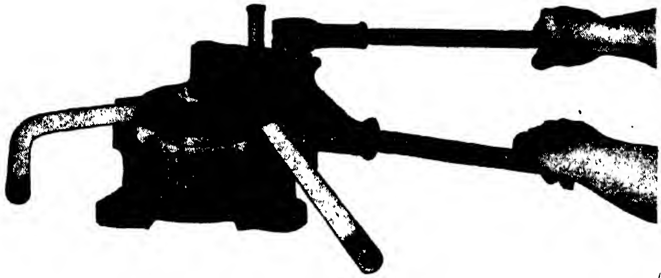


FIG. 14.—BENDING A 1-IN. STEAM PIPE USING A RATCHET-GEARED UNIVERSAL BENDER

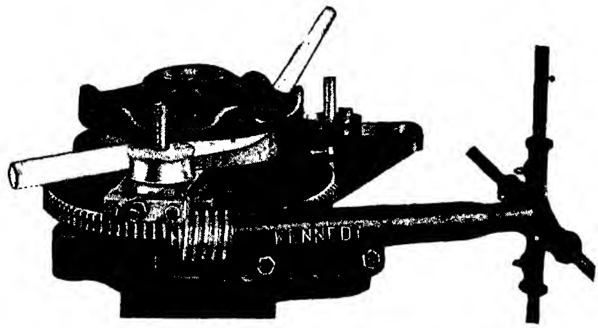


FIG. 15.—UNIVERSAL BENDER, BENDING A 1½-IN. STEAM PIPE

Ts, channels, etc., the same method is used, but the former is made to conform to the particular section being bent, and the pressure of the top plate is again used to maintain an undistorted section with or without the extra protection of a back former.

IRON PIPE BENDING

Included under this heading are all standard water, gas, and steam pipes in iron or steel, butt-welded, lap-welded, and solid drawn tubes of equivalent thickness or thicker.

Pipes up to Half an Inch

The bending machine (Fig. 12) must have a substantial fixing, and should be firmly bolted to a bench, which must be anchored to the floor in such a position that there is sufficient room to swing the longest lengths of pipe that are to be used. Although not always essential, it will be found more convenient if the operator has room to move on all sides of the machine.

To make the bend, the screwed top plate is taken off, and the former, of the required radius and size to suit the tube to be bent, is placed over the screwed centre mandrel. The top plate is then replaced and screwed about half-way down. The pipe is inserted in the machine between and against the former and the stop. The top plate is then screwed down until it clamps the pipe (it is only necessary to screw it down hand tight). The top arm is placed in the hole in the centre mandrel, and the lever is pulled so that the roller comes in contact with the pipe, which is thus forced round the former to make the bend. When the pipe is bent to the required angle, the plunger is pushed down to engage in the nearest hole in the top plate, and the lever returned to its original position. This automatically unscrews the top plate, which has become tightly locked by the pressure exerted by the pipe endeavouring to flatten. (*Note.*—It is not necessary to remove the top plate from the mandrel for every bend, as only a quarter-turn is required to free the pipe.)

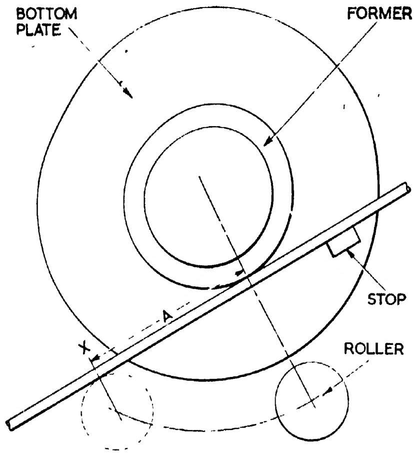


FIG. 16.—ROLLER ADJUSTED RIGHT BACK. CONTACT POINT AT X, GIVING LONG LEVERAGE, DISTANCE A

Pipes up to One Inch

The bender (Fig. 13), besides differing from the last machine in size and capacity, is fitted with a slightly different top arm, which takes two levers, so that two men can exert bending pressure if desired on the maximum-size pipes.

A similar machine is shown in Fig. 14, but this is fitted with ratchet gearing for easier working. The bending is done exactly as on the smaller machine.

When bending the smaller sizes of pipe it is obviously unnecessary to use the gearing, as they may be bent easily by direct pull. The ratchet is removed and the bend made by pulling the long lever. When using the gearing on larger and heavier pipes, the long lever is only used to hold the bending roller up to the work, and the actual bending is done by the increased leverage given by the ratchet lever and gearing.

Pipes up to Two Inches

These can be bent on the Universal bender shown in Fig. 15. A similar machine but power driven is shown in Fig. 40. The machine is fitted with worm gearing, driving the gearwheel upon which the bending roller is mounted. The bends are made in the same way as on the smaller machines, except that the bending roller is rotated by means of a worm and pilot wheel in place of the direct lever. The top plate is unscrewed by the roller stud coming in contact with a tommy bar inserted in the top plate when the wormwheel is reversed.

To take the resistance to the bending force, stops are provided to suit the work.

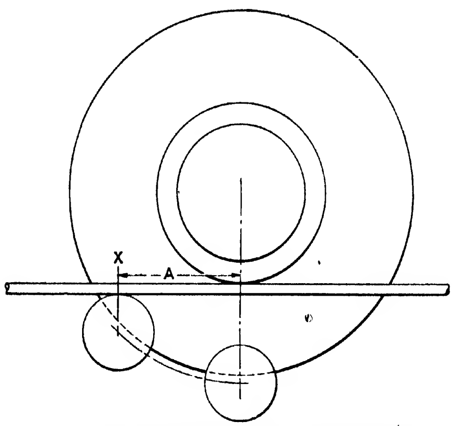


FIG. 17.—ROLLER ADJUSTED UP. CONTACT POINT AT X, GIVING SHORTER LEVERAGE, DISTANCE A

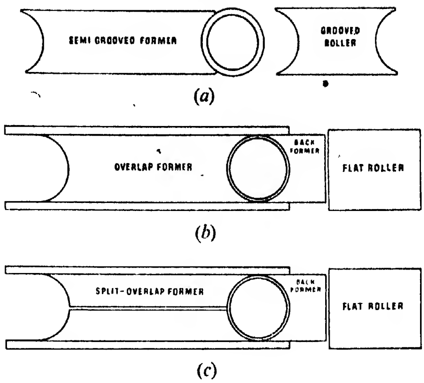


FIG. 18.—(*a*) SEMI-GROOVED FORMER AND ROLLER FOR BENDING THICK PIPES; (*b*) FULLY OVERLAP SOLID FORMER, BACK FORMER, AND FLAT ROLLER FOR BENDING LIGHT-GAUGE TUBES; (*c*) FULLY OVERLAP SPLIT FORMER, BACK FORMER, AND FLAT ROLLER FOR LIGHT-GAUGE TUBES

The stop should be lined up with the pipe when it is touching the former in a position ready for bending.

It should be noted that a back former (a straight bar grooved to fit the pipe) is supplied for 2-in. steam pipe only. This is used with a flat roller.

The worm-driven machine described is fitted with a lateral adjustment to the bending roller, which is fitted to a slide, free to move towards or away from the bending centre, and so altering the leverage exerted on the pipe. The farther out the roller slide is moved, the farther along the pipe will the roller make contact and transmit the bending pressure, and the greater will be the leverage obtained (Fig. 16). Thus, less force is required to turn the handle when the roller is right back than when it is screwed up closer to the pipe as in Fig. 17.

When a small-radius former is used, it has the same effect as screwing the roller back, as the leverage length is increased, so that the roller may be screwed closer to the tube to lessen the leverage length, or bending lead, because, if there is too much lead, the pipe may tend to "bow" between the points of contact of roller and former.

LIGHT-GAUGE-TUBE BENDING

It has been explained previously how heavy-gauge iron and steel pipes, such as gas and steam pipes, are bent, and how, on the "Kennedy" machines, only the screwed top plate prevents the pipe from flattening. In the case of this heavy-gauge pipe, the walls are thick and strong enough to stand up to the bending while supported at three points by the top and bottom plates and the former (Fig. 18*a*).

In the case of thinner-walled tubes (and when a thicker tube is to be bent to a sharp radius), further protection is needed, as there is naturally a greater tendency for the thinner walls to collapse and distort. This greater protection and support is given by a special type of former with overlapping flanges, together with the use of a back former. The former is accurately turned to an exact fit round the tube (Fig. 18(*b*)). Thus the tube is protected on three sides by

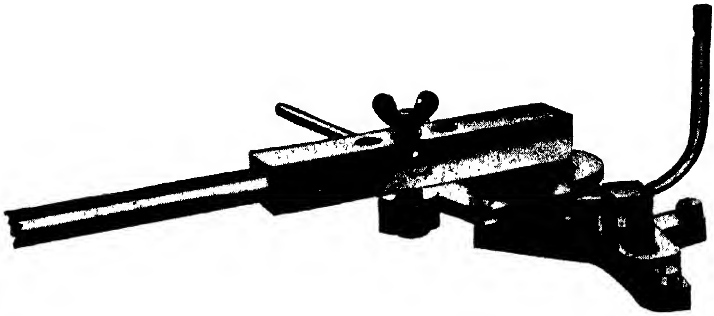


FIG. 19.—LIGHT-GAUGE-TUBE BENDER FOR TUBES UP TO 1 IN. DIAMETER

the former. The fourth and outer side is supported and reinforced by the back former, an intermediate bar between the tube and the roller, which is grooved to fit the tube, and with its edges fitting into the flanges of the former. This back former, besides protecting the tube from indentation by the contact of the roller, also assists in maintaining the true section of the tube, as it will be seen in Fig. 18(*b*) that the tube is totally enclosed at the bending point. It will be observed that a flat roller is used instead of a grooved one, as it comes in contact with the flat side of the back former instead of the rounded side of the tube.

Tubes up to One Inch

A simple machine to bend light-gauge tube in copper, brass, and steel up to 1 in. bore or outside diameter is shown in Fig. 19. All the movable parts are clearly marked with the tube sizes, so that the changing of formers and making the bends is easily and quickly accomplished. The required former is slipped over the centre mandrel (the top arm having been lifted off to allow this) and located by the small peg on the body, which prevents the former from turning. The roller is placed in one of the three holes in the top arm according to the size of the tube, and the stop is put in the most convenient stop hole in the vase of the machine. The tube is inserted in the former groove and against the stop, the back former placed between the tube and the roller, and the bend made by pulling the lever. The roller should not be allowed to run off the end of the back former or an indentation will be made in the tube. When the roller approaches within an inch of the end of the back former, the latter should be pulled farther forward along the tube. The lever is returned to its starting position after the back former has been removed and the bend withdrawn from the machine. If the bend is in the middle of a long length, lift the top arm off first, so that the bend has only to be moved clear of the former groove to be removed easily. This prevents any necessity for passing a long tube right through the machine. This machine, having the roller stud in fixed position, i.e. with adjustment for standard formers only, cannot be used with formers of non-standard radii, as the bending leverage, or lead, as has already been explained,

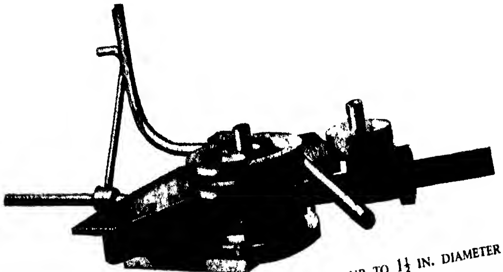


FIG. 20.—LIGHT-GAUGE-TUBE BENDER FOR TUBES UP TO 1½ IN. DIAMETER

would probably be too great to produce a satisfactory bend, unless the space between the back former and roller was packed out. Therefore the machine shown in Fig. 19 is recommended, as the bending roller is adjustable and can be screwed up to suit any intermediate radii.

Tubes up to One and a Half Inches

The bender in Fig. 20 will bend copper and brass tubes from ⅜ in. × 20 g. to 1½ in. × 17 g. and up to 1¼ in. × 17 g. steel tubes on standard formers (Fig. 18 (*b*)). Lighter-gauge tubes can be bent to a larger radius than the standard, and, if loaded, to a smaller radius. An attachment can be fitted to this machine to convert it to a drawbar bender (minimum radius 1½ × diameter of tube) (see page 383).

The reader is now conversant with the method of bending, which also applies to this machine. A little care, however, is needed in making the correct adjustment to the bending roller. The correct adjustment when using standard formers should leave approximately a $\frac{3}{32}$-in. gap between the roller and the back former when the bending arm is at right angles to the tube, but it should be understood that the correct leverage or "lead" varies with the material being bent, the radius of bend, the gauge and temper of the tube, and cannot be obtained by mechanical means to cope with these varying conditions. Usually a $\frac{3}{32}$-in. gap will give the best results, but if it does not, the bend should be examined. If the bend is kinked in the throat, the roller should be screwed up half a turn closer to the work. This increases the bending pressure applied to the bend and so prevents kinks and puckers forming.

If, on the other hand, there are no kinks, but a bump is apparent at the start and finish of the bend, the roller should be screwed back half a turn from the tube, and the bend made.

Points to be Watched

The roller should not be moved more than one half turn of screw at a time, as if withdrawn too far the bend will show a flattened back or "heel." This

procedure may appear a little complicated, but in practice, after a little experience, it will be found quite simple.

The start and finish marks referred to are caused by the pressure that has to be applied in making the bend. They cannot therefore be entirely eradicated, but they can be reduced to an absolute minimum by the correct adjustment of the bending roller. The closer up the roller is the greater the pressure and the more apparent the marks; while the farther back it is the more liable is the tube to distort. Therefore, the roller should be adjusted up no farther than is necessary to prevent throat puckers.

It will be noticed that on this machine the flat top plate is large enough to accommodate any special jig or fixtures that may be required. This plate, of course, also houses the stop. A series of holes being drilled on either side so that left and right bending may be done, as in some jobs with various bends at different planes to one another, it would be impossible to make them all with right-hand bends. For all bends the stop should be placed on the hole nearest to the start of the bend, and, as it is double sided and the shank placed out of centre, turned to present the most suitable side to the tube. This machine is fitted with a length gauge which can be instantly adjusted by hand to set the tube in the required position. Also, round the machined edge of the base, a series of small holes are drilled to take a small rectangular check stop—a pin fixed eccentrically to a rectangular block. This check stop is used to stop the bending arm at the desired angle of bend when several uniform bends are required, the eccentric block giving four different positions in each hole. Final fine adjustment can be made by adjusting the bending roller up or back very slightly. This adjustment must be very slight, otherwise the correct leverage would be affected.

DRAWBAR BENDING

So far, compression bending only has been described, but no article on light-gauge-tube bending would be complete without a full description of this method, the basic principles of which were mentioned briefly on page 372. As explained, by this method the tube is clamped to the former and the bend made by rotating the former and drawing the tube against a stationary shoe or roller.

As a rough guide, compression benders will bend tubes to a radius of approximately $3 \times$ diameter of tube. The draw bender, with the aid of an internal mandrel or drawbar, will produce bends to a radius of approximately $1\frac{1}{2} \times$ diameter of tube.

The former itself is half grooved, and instead of being circular, has a straight portion to which the tube is clamped (Fig. 21). To this former is fitted a lever, by which it is rotated. The drawbar is anchored at one end, the other end is rounded. This drawbar has a clearance in the tube of 0·01 in. (*Note.*—This end can be in the form of a detachable nose, and can be fixed to a tail of smaller diameter bar.)

The tube is slid over the drawbar, clamped to the former, and the roller housing is adjusted so that the rollers press the sliding back former against the

tube. The lever is pulled, and the tube bends round the former as it is pulled off the drawbar.

Points to watch in draw bending are:

1. The amount of advance of the drawbar beyond the bending point. The actual advance of the parallel end (ignoring the rounded portion) is the important dimension.

This of course varies with different sizes and gauges, but it is usual to try a bend with say $\frac{1}{4}$ in. advance, and to modify this after trial.

2. The clamp holding the tube to the former must be accurately made, as if it is not absolutely effective the tube will slip and the bend be spoilt.

3. The degree of pressure needed on the rollers or sliding back former varies with the gauge of tube. While the tighter this is the greater is the ironing-out effect on the inner side of the tube, it is obvious that more friction is set up and more strain on the clamp.

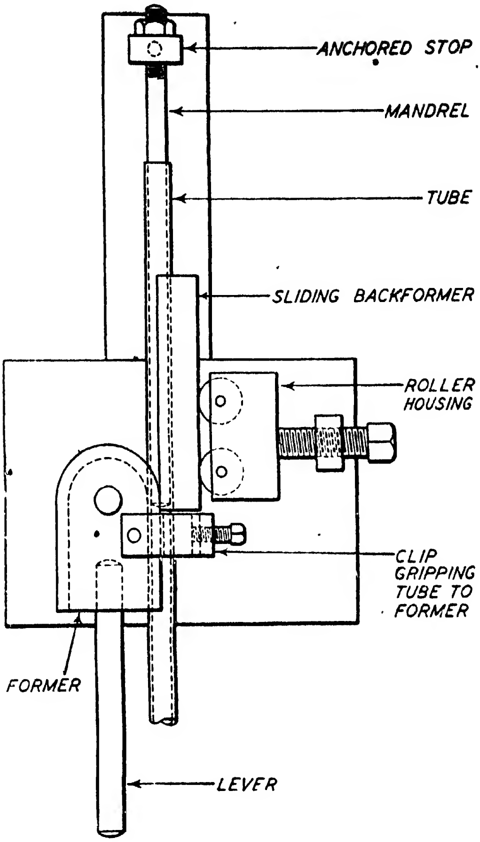


FIG. 21.—GENERAL ARRANGEMENT OF A DRAW-BAR MACHINE FOR BENDING LIGHT-GAUGE TUBES

Before bending, the inside of the tube should be oiled.

DRAW BENDING ON A COMPRESSION BENDER

The compression bender, the No. 12 Kennedy tube bender, can be used for both compression and draw bending.

Compression bending has already been described. To convert this machine to draw bending, a specially designed attachment can be supplied which is fitted to the machine without any alteration. This accessory is shown in Figs. 22 and 23. It consists of a drawbar tail (*a*); tail support and anchor (*b*)—this is

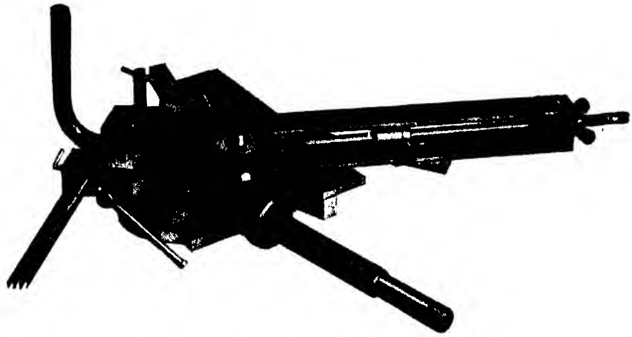


FIG. 22.—STANDARD COMPRESSION BENDER FITTED WITH A DRAW-BAR ATTACHMENT FOR SHARP RADIUS BENDING

put into one of the stop holes in the machine; tube clamp and lever housing (*c*); angle check stop (*d*), and grooved roller (*f*), and is used with suitable tools, i.e. grooved former (*e*) and drawbar nose, which is a sliding fit in the tube and is attached to the tail.

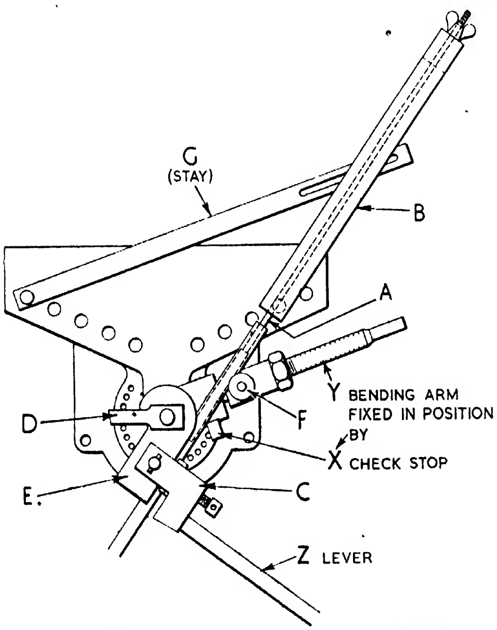


FIG. 23.—DRAW-BAR ATTACHMENT FITTED TO A STANDARD COMPRESSION BENDER

The normal bending arm *Y* is locked by the check stop *X*, and the grooved roller *F* (in place of the standard flat roller) acts as the bending resistance. Thus the normal rotating bending arm is now stationary. The lever is taken from this arm and fitted to the lever housing in the former and is used to rotate the former when bending.

Tubes up to Two Inches

Copper tubes up to 2 in. diameter can be bent on the machine shown in Fig. 27. This machine is a large edition of that shown in Fig. 22, and is used chiefly by plumbers and electricians who wish to take the machine on the job.

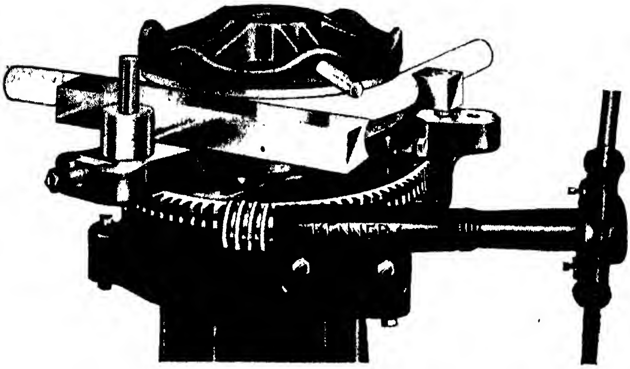


FIG. 24.—BENDING A 2-IN. LIGHT-GAUGE TUBE WITH A UNIVERSAL BENDER

For shop use and production a worm-driven machine is advised, as not only can steel tubes be bent with ease, but larger and heavier tubes can be bent on a Universal machine. The operation of bending is the same as on the smaller compression benders described, but the drive is through a worm gearing instead of by a direct lever. Fig. 24 shows light-gauge tube being bent on a Universal bender.

A stop, shaped to fit the tube or V-grooved, should be used. When bending to minimum radii on these machines, it is often advantageous to drill the bottom plate to take the stop, as the holes in the stop bracket are too far away from the start of the bend. Also, by putting the stop close up on the plate, double sets can be made with minimum straightness between the bends. A diagram of the set-up for light-gauge tubes on a Universal bender is shown in Fig. 26.

The sharpest radius that can be bent depends on the gauge, the size of the tube, and, in the case of the machines now being described, upon the size of the centre mandrels. It is at once apparent that no radii as small or smaller than this can be bent on the standard machines. It is, however, possible to have a smaller-diameter detachable mandrel fitted as a special job, but it should be remembered that, because of the resultant loss in strength, the maximum capacity of the machine is reduced in some directions.

The bending of light-gauge tubes larger than 2 in. diameter and smaller tubes if bent to a sharper radius than the unloaded limit must be (*a*) loaded with a suitable filling and bent as described, or (*b*) bent on a drawbar machine using an inside mandrel.

The various methods of loading are explained below.

TUBE LOADING

When a tube is required to be bent to a radius sharper than the "safe" radii given in the chart and where a machine using an inside mandrel is not

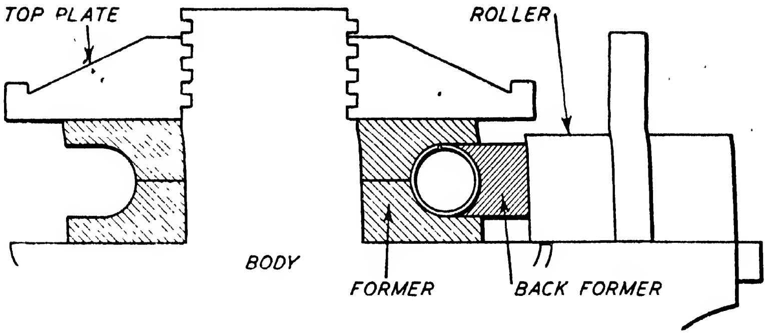


FIG. 25.—SHAPE OF TOOLS REQUIRED TO BEND LIGHT-GAUGE TUBES

available, the tube should be loaded with a suitable medium and bent on an ordinary bending machine, using overlap formers.

The success of such bends depends on the efficiency of the loading, and care should be taken to ensure that loading is correctly done and is capable of supporting the tube and so maintaining the true section. There are several methods of loading, and the most usual of these are as follows:

Sand

Sand as a loading is ideal, provided the bend required is not too sharp. Silver sand is very cheap, clean, and may be obtained from any ironmonger. The sand when purchased is in a moist condition, and should be dried in a shallow tray over an ordinary fire, and then stored in a drum and kept in a dry place.

The great advantage of sand is the ease of filling and emptying, besides which, it is clean to handle. The tube to be bent should be plugged at one end by a wooden plug or by a wad of coarse sacking. The sand is then poured into the tube until it is full and the tube tapped with a light mallet. It will be found that the tapping will cause the level of the sand to drop about a quarter of the way down the tube; the space so caused should be refilled with sand, and the tube again tapped all over, working from the bottom upwards. This procedure must be repeated until there is no visible drop in the level of the sand after tapping. After hammering in the other plug tightly, the tube should again be tapped and then the plug hammered farther in. If the tube, when struck with the mallet, gives a clear ringing note, the tube is properly loaded. If not, more tapping and hammering of the plug is needed.

Pitch and Resin

A mixture, consisting of equal parts of pitch and resin, should be melted in a suitable vessel, poured into the plugged tube and allowed to cool. Sufficient of the mixture should be in readiness to enable the whole of the tube to be filled in one operation.

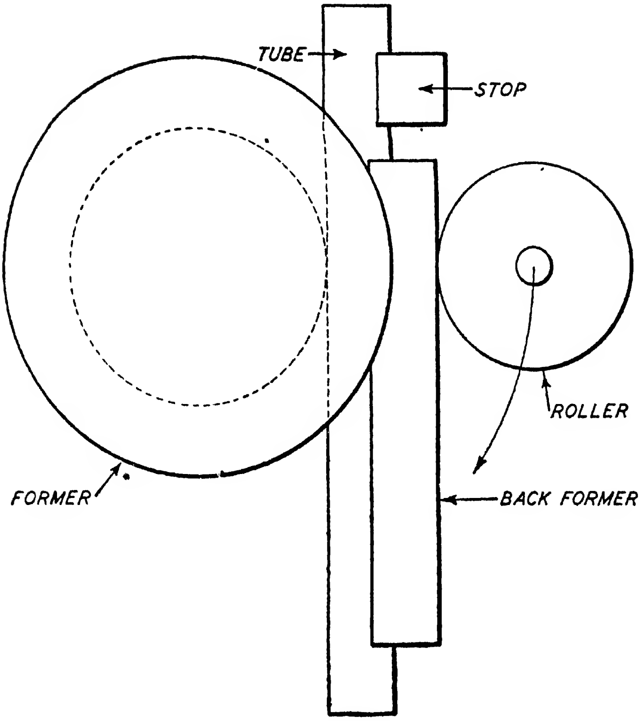


FIG. 26.—SET-UP OF TOOLS FOR BENDING LIGHT-GAUGE TUBES ON A UNIVERSAL BENDER

This loading is more efficient than sand, but the loading and unloading operations, involving the melting, are naturally messy, and the process takes longer than sand loading if there are only one or two bends to be made.

Lead

Lead loading is very efficient, but has the drawback of pitch and resin, being very messy in use, and the melting out of the lead after loading is a slow job.

The tube should be plugged, or stood upright on a cold metal plate, and the molten lead poured in. The lead should be in a thoroughly molten state, as, if the metal is chilled, the tube will not be filled solid. After each ladle of lead is poured in, a blowlamp should be played on the tube to ensure that the successive charges of lead are united into a homogeneous filling. Owing to shrinkage after cooling, a crater is formed at the top of the loading, and this portion should be reheated by the blowlamp and sufficient molten lead poured into the crater until the tube is full.

Low melting-point Filler

This is a metal alloy which melts in hot water. There are several proprietary alloys on the market, and these have many advantages. The low melting-point enables easy filling and emptying.

Tubes should be cleaned, plugged, oiled, and filled with hot water. The filler is then poured into the tubes, thus displacing the water. The filled tube must be quenched immediately in cold water and should then be left to attain

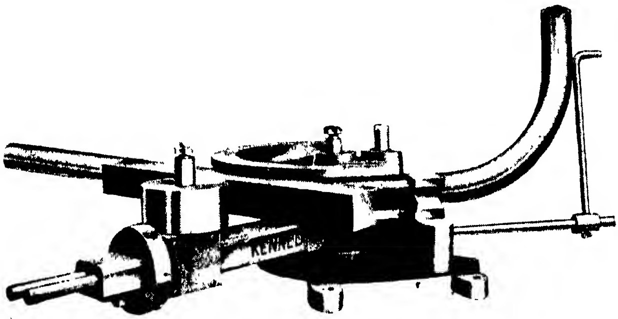


FIG. 27.—DIRECT MILL BENDER FOR BENDING LIGHT-GAUGE TUBES UP TO 2 IN. DIAMETER

room temperature. Before bending, the tube should be warmed to about 100° F.

The bending must be done with a slow regular pressure.

SECTION BENDING

Many new and varied sections are appearing in different trades almost daily, and the majority of these have to be bent.

A study of this section, which describes the bending of many different sections, such as flats, angles, Ts, and channels, will enable the operator to make suitable formers to bend and variations of such sections.

Flat Bars

Flat bars of steel, brass, copper, and other metals are used for many purposes, and those of copper are mostly used for switchgear and other electrical work.

A flat bar can be bent in two directions, i.e. with the wide surface on the inside of the bend (described in this article as bending on the flat) and with the narrow edge on the inside of the bend (described as bending on edge) (Fig. 28).

Edge Bending

Assuming that the size of the bar is 1 in. $\times$ $\frac{1}{8}$ in., it is obviously a simpler matter to bend it on the flat as shown in Fig. 28 (a) than to bend it on edge as in Fig. 28 (b), and without the use of a machine the bar would have to be bent hot and then hammered flat to disperse the puckers that would form while bending

on the inside of the bend, owing to compression. It is, however, a very simple operation indeed to make this type of bend without any pucker whatever, on the "Kennedy" Universal machines.

The strip can be inserted into the machine in the usual way without any former, as the strip can be bent round the centre mandrel itself, the base of which is left plain. The top plate is screwed down hand tight, the bend made and removed in the usual way.

This bend will, of course, follow the shape of the mandrel, which is, on the No. 1 Universal, 2½ in. diameter (Fig. 29), so that the inside radius of the bend allowing for spring is 1¼ in. If a larger radius is required, a former should be used. This is simply a plain ring of the required radius, and of a thickness slightly less than that of the material being bent.

This former is used in exactly the same way as a pipe former. Another method is to bend a piece of strip round the mandrel, then use this bend as a former, bending round the outer edge of the former strip. This method is not, of course, so good as a turned former, as, owing to the inside of the strip being thicker, the top plate does not quite grip the material being bent; but if the strip is not thinner than ⅛ in. it is quite practicable.

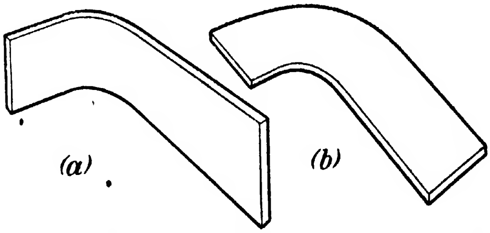


FIG. 28.—FLAT-STRIP BEND: (a) ON THE FLAT, (b) ON EDGE

To avoid any tendency of the strip to bow between the point of former contact and the bending roller, it is recommended that a back former be used between the strip and roller. This can, in some cases, be a short piece of the actual section itself, or a short length of mild-steel plate slightly thinner than the section being bent. This back former is used in the same way as the grooved back formers employed for light-gauge tubes. Note that it is not necessary to fill the space between the section and the roller completely. The gap to be left varies with the size of the flat bars, the heavier the bars the larger the gap, so that more leverage is obtained to make the bend.

As the base of the machine is 6 in. diameter, the use of radius formers is limited; but if a large sweep is required, the following information may be useful. The bar to be bent should be marked in chalk every 2 in. and put into the machine with the top plate screwed down very loosely on to the bar, a slight bend made, and the bar moved into the machine a further 2 in. and another slight bend made. This, of course, needs a certain amount of practice by trial and error to obtain the required result, but it is often useful in getting a radius that would otherwise be too large for the machine.

The larger Universal machines have naturally a greater capacity, and the

FIG. 29.—SMALL UNIVERSAL BENDER, BENDING STEEL STRIP ON EDGE

largest will bend mild-steel bars on edge up to 2 in. × ½ in. and copper bars up to 3 in. × ½ in.

Flat Bending

It is, of course, a much simpler job to bend a flat bar with the wide surface on the inside of the bend, because the material offers very little resistance, and because the structural alteration in the metal is so slight. Thus, little or no protection is required to keep the section in its proper shape.

Flat bends can be made on most benders, and the simplest machines for the job are the bar benders. If the Universal machines are used, the top plate should be removed and the bars bent round a plain former. Usually a back former is not required, unless bending a wide section, when a back former of suitable size will sometimes avoid the necessity of a thicker roller, and incidentally will enable shorter lengths of bar to be bent, as the leverage is shortened by the insertion of a back former. If quantities of bars are to be bent, it is recommended that both a back former and a roller of the same thickness as the height of the bar should be used. The stop should be made high enough to make full contact with the bar, which would otherwise be distorted.

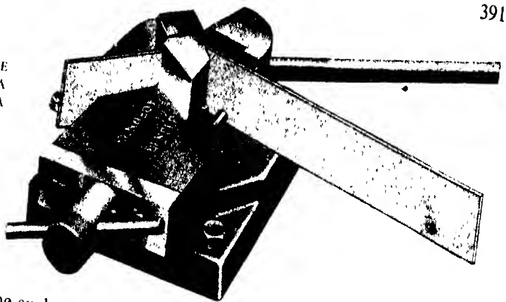
When bending bars on the flat to a small radius, the face of the former should be made slightly convex, as it will be found that the edges of the bar tend to fall outwards a little.

It will be understood that the minimum radius that can be bent is governed by the radius of the mandrel, plus the thickness of the former that is fitted to the machine being used, and therefore a very sharp radius bend or a sharp corner bend should be made on the machine described below.

Sharp-corner Flat Bending

Flat strip can be hammered to a right-angle corner in a vice, but two such bends close together is not so easily done by hand. These bends can best be

FIG. 30.—MACHINE FOR BENDING A FLAT STRIP TO A SHARP RADIUS



made on a machine such as that illustrated in Fig. 30. This bender consists of a cast-iron base upon which is mounted the adjustable mandrel or diepost, the fixed stop, and the bending block.

The diepost is screwed up to grip the bar between it and the fixed stop, and it will be seen that the diepost, by being screwed up and gripping the bar, is always in the correct position for bending irrespective of the thickness of bar. The fixed stop acts in exactly the same way as the stop on any other bender, while the bending block pivots on a centre, found on the intersection of the two outside edges of the bent bar when produced.

Thus it will be seen that the diepost is always out of centre, and that the bending block, unlike the roller on the other types of bending machines, does not travel along the bar away from the centre. Actually there is very little movement at all between the outside face of the bar and the face of the bending block, and instead of the bending block moving away from the centre, it will be found that the bending exerts no drag on the bar at all, as the relative movement is in the opposite direction.

The method of bending is self-evident. The bar is placed in the machine between the stop and the diepost, which is tightened up to grip the bar, the lever is pulled, and the bend made.

It will be noted that the machine is designed with an upper and lower deck, the diepost being cut away in such a manner so as to allow close bends to be made on the upper portion (Fig. 31). The stop block is reduced in size at the top to enable close bends to be made.

The edge of the stop block is calibrated in inches and eighths, and all measurements are to be taken from the back of the bend. A length gauge is provided, which, if not long enough for the job in hand, can easily be replaced by a longer length of ½-in. bar, bent in the machine to a right angle at one end. The bending quadrant is also calibrated in degrees, and an adjustable gauge is supplied which can be set to produce bends at any angle up to 90°.

If a dead sharp corner is not required, the hardened-steel blade on the die-post should be reversed to present the radius edge. Bars of the larger sizes should always be bent round this slightly radius edge. When using this upper

deck, it will be found convenient to place a short length of $1\frac{1}{2}$-in. bar, slightly thinner than the material bent, between the diepost and the stop block, so that the work is kept up to the level of the upper deck.

It should be noted that the hardened bending blade can be placed in two positions. This may be screwed in position nearest to the centre for light work, and for heavy work fixed in the farthermost position from the centre. This outside position gives more leverage for bending the heavier work and thus less strain is thrown on the machine. The inside position gives a lighter bend on light material.

The positioning of the bending blade can be clearly seen in Figs. 30 and 31.

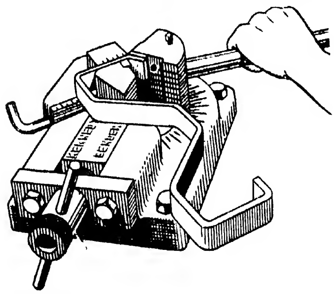


FIG. 31.—FLAT-BAR BENDER FOR MAKING BENDS CLOSE TOGETHER ON THE TOP DECK

Angle Bending

It is generally recognised that the bending of an angle section is one of the most difficult bending operations to perform successfully without a machine.

The reason that an angle is so difficult to bend is because it is an irregular bending section, i.e. the two flanges each offer a different resistance to bending.

We will first of all consider the case of an angle bent with the flat or horizontal web on the outside of the bend. The bending former, which is described later, comes in contact with the upright web, so that the whole of the horizontal web when being bent is in compression (Fig. 4), and the remainder of the section which has to stretch is approximately half the vertical web only. Naturally, it follows that there is very much greater resistance to bending than the vertical web, and it is this unequal resistance which causes distortion. Thus, if an angle section is bent with the horizontal web (or flange) on the inside without any protection whatever, the following tendencies would be apparent:

1. The flange which was bent on edge would pucker in an attempt to disperse the surplus metal on the inside.

2. The upright web, not having the resistance of the flange, would endeavour to take a short cut (instead of stretching) across the bend and would fall inwards. These effects are shown in Fig. 32 (*a*).

When the angle is bent with the flange on the outside bend, the flange, which is being bent on edge, has to stretch all over, as the upright web (in contact with the former) resists compression and forces the structural alteration to take place in the flange. The upright web falls outwards, taking the line of resistance (Fig. 32 (*b*)).

This irregular bending resistance is responsible for another troublesome tendency, i.e. a twist or "wind" which appears in the bend.

It will be gathered, from the foregoing remarks, that it is no mean feat to counteract the unfortunate distorting tendencies of an angle section when being

bent and to produce a good bend; and that the work of an angle smith is obviously a highly skilled craft.

The angle smith, of course, does his bending hot, and the angle is bent round a former, the puckers hammered down, and the angle forced into its correct section by shrewd hammer blows. It is interesting to note that the smith imparts an artificial distortion to the angle by putting a twist or "wind" in it before bending, but in the opposite direction from which it takes while being bent. Thus, when the bend is made, the twist is neutralised and the bend is flat.

Large-radius bends from, say, 20 in. radius, can be made in ordinary angle rolls, but the bends rolled in this manner, and especially those with the flange on the inside, are not very satisfactory unless the radius is very large. It will

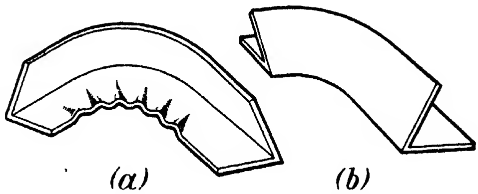


FIG. 32.—NATURAL DISTORTING TENDENCIES WHICH OCCUR WHEN ANGLE SECTION IS BENT

(*a*) With the flange on the inside of the bend; (*b*) with the flange on the outside of the bend.

also be found that this is a slow process unless power-operated rolls are used and that it does not lend itself to easy measurement bending.

The "Kennedy" method of bending angle sections cold is the only method whereby angles can be bent cold to a small radius and still maintain the original section after bending, free from puckers or any distortion requiring "dressing up" after bending.

Angle Bending by the "Kennedy" System

The "Kennedy" method of bending angle sections cold is extremely simple and effective, and is evolved from a careful study of all the distorting tendencies of an angle section when being bent. These tendencies are restricted and counteracted by the following means.

The angle is bent round a former of the desired radius, which is placed on the Universal machines in the usual way between the top and bottom plates. This former is shown in position in Fig. 33 (*a*), with the angle ready for bending, together with the back former. The illustration shows the arrangement for a bend with the flange on the inside. The top plate when screwed down comes in contact with the top of the former, so that pressure is applied to the flange (which is being bent on edge) and prevents puckering. This portion of the angle corresponds with the bending of a flat bar on edge.

It will be noticed that the former and back former are not shaped to follow the profile of the angle section, but are splayed. This splay (which in the illustration is exaggerated for clearness) is to counteract the tendency of the angle to fall inwards, and it should be mentioned that to obtain the full effect of this splay, the bending roller should be screwed up tightly to the back former. (*Note.*—On the smaller Universal machines, without screw adjustment

to the bending roller, the back former should be a tight fit between the section and the roller, i.e. the bending leverage should be as short as possible.)

Directly the bend is begun, the back former is forced inwards towards the angle section by the pressure of the bending roller, and the splay on the former causes the upright web to be distorted, as it is forced to assume a similar splay to that on the former, which, it should be noted, is splayed in the opposite direction to which the angle normally tends to fall.

Thus the angle is purposely distorted slightly in advance of the bending point. The natural distortion or falling in takes place at the bending point, and neutralises or counteracts the artificial splay imparted by the former, so that the angle is returned to its original square section. In short, the angle is artificially splayed in one direction, and this is brought back to normal by the natural distortion caused by bending.

It should be understood that the amount of splay on the former and back former varies slightly according to the size and thickness of the angle section being bent, but it will be found that a 5° splay is usually sufficient, because the amount of splay imparted to the angle can be controlled by the amount of leverage given to the bending roller. If the roller is screwed up tightly, the maximum splay is imparted, but if it is not screwed up tightly less splay is given to the angle. It is therefore possible to adjust the bending roller to obtain the exact amount of artificial distortion, which results in a true section bend.

The tendency of the angle to wind or twist is prevented by the top and bottom plates, which act as guides and keep the angle on one flat plane. It is always advisable to use as large a top plate as possible.

It will be realised that if a bend is made at or close to the maximum radius of the machine, the top plate will not project very far beyond the angle, in which case it will be found beneficial to place a plain plate of larger diameter under the top plate.

One of the great features of this system is that it is possible to bend the angle with the flange on the outside, and on the inside, of the bend with the same former and back former. It is only necessary to turn them upside down to present the splay in the opposite direction. When the angle is bent with the web outside, the whole of the flat web or flange has to stretch, and therefore it need not be clamped to prevent puckers. The back former, being an easy fit between the web and the top plate, is sufficient to keep the flange from rising (Fig. 33 (*b*)).

The tendency of the angle is now to fall outwards, and the splay of the former, which operates in the opposite direction, imparts a distortion which is corrected in bending in the same way as before, for "web in" bending.

The following points should be noted:

1. When the angle being bent "web in" is in position in the bender, with the top plate screwed down, there should be a clearance between the bottom plate and the underside of the former. This is to ensure that the web is gripped between the former and the bottom plate to prevent puckering.

2. A clearance must be left between the top plate and the top of the angle,

otherwise the upright web will be gripped instead of the horizontal flange.

3. These clearances must be as small as possible, so that the angle is not given room to get out of the flat plane.

Fig. 34 shows the arrangement of the former and back former in the machine to bend angle with the flange on the inside of the bend, while Fig. 35 shows the former turnover for bending angle with the flange on the outside.

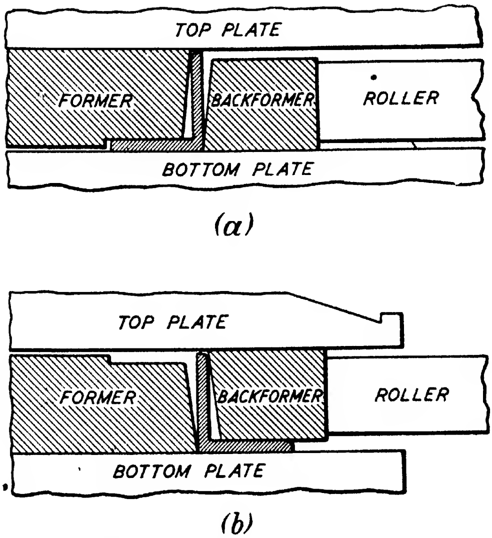


FIG. 33.—SHAPE OF TOOLS FOR BENDING ANGLE SECTIONS
(*a*) With the flange on the inside; (*b*) on the outside of the bend.

General Instructions for Angle Bending

1. Place the former over the mandrel as shown in Fig. 34 for "flange inside" bending, or, as shown in Fig. 35, for "flange outside" bending.
2. Insert angle in the machine against the former and the stop.
3. Screw down the top plate hand tight.
4. Revolve the gearwheel until the bending bracket is at right angles to the angle section.
5. Place the back former in position between the angle and the bending roller, making sure that the splay on the back former coincides with that on the former.
6. Screw up the roller hand tight, plus one half turn with a spanner.
7. Bend to required angle.
8. Undo the top plate by inserting the tommy bar and engaging this with the roller stud by reversing the bending motion (Fig. 16).

Note.—If, on removing the bend from the machine, it is found that the section is not square, it may be put right by replacing in the machine and re-rolling with the bending roller screwed up more tightly. This applies only if the section has fallen inwards. If it has fallen outwards, subsequent bends should be made with less leverage, i.e. with the roller screwed back a little.

The standard stops can generally be used when angle is being bent. It will be noted from Fig. 35 that when bending with the angle flange on the outside of the bend, the stop lays on the flange and the resistance is taken on the upright web.

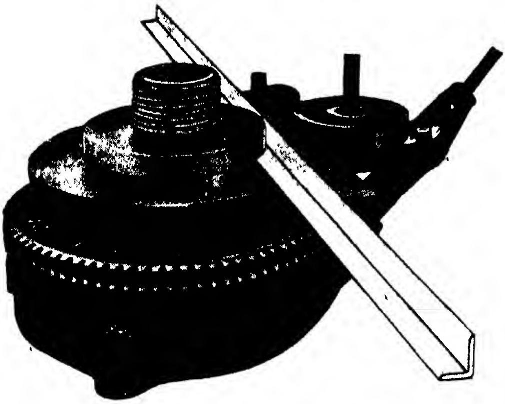


FIG. 34.—SET-UP FOR BENDING ANGLE SECTION WITH THE WEB INSIDE

When bending to a minimum radius it is more advantageous to drill the bottom plate and to use a special stop close to the bending point than to use the stop on the stop bracket. Stops should always be placed as close as possible to the start of the bend, as this obviates any tendency of the work to bow. A suitable stop for use when the bottom plate of the machine is drilled can be easily made by cutting a piece, about 2 in. long, off the back former, this should be drilled and a shank fitted.

BENDING ANGLE RINGS.—The simplest method of making complete angle rings is to bend two U-bends in the ordinary way, cut off the straight ends, and weld the two halves together.

BAR BENDING.—The bending of round and square bars is a comparatively easy job, as there is no question of support to worry about. It is merely a question of the machine being strong enough to do the work.

However, it is important to produce the exact dimensions in the component being bent, and the method of obtaining dead-measurement bending is fully described on page 398.

Two typical bar-bending hand machines are shown in Figs. 36 and 37, and a power-operated bar bender for bending concrete reinforcement is shown in Fig. 39.

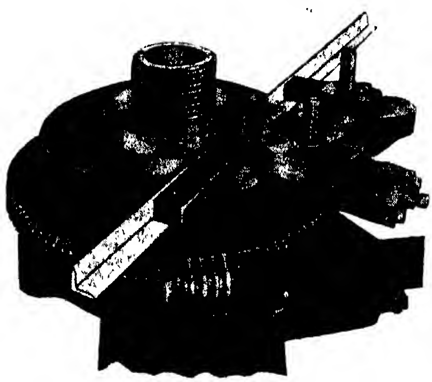


FIG. 35.—SET-UP FOR BENDING ANGLE SECTION WITH THE WEB OUTSIDE

Channel Bending

Channel sections in brass and steel are quite common, and are bent in order that they may be used for such purposes as bottom tracks for sliding doors, windscreen and mirror frames, etc.

A channel section can be

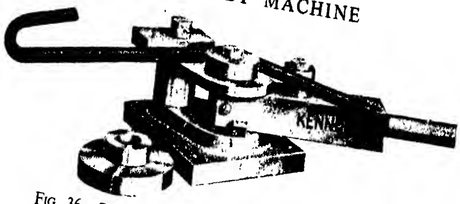


FIG. 36.—SMALL BENDER FOR BARS UP TO $\frac{5}{8}$ IN. DIAMETER

bent in three directions, i.e. with the open mouth of the channel on (*a*) the inside of the bend, (*b*) the outside, (*c*) with the mouth upwards (Fig. 38).

If the bend (*a*) is considered, it will be realised that (1) both the inside flanges are compressed, (2) that the back has undergone very little alteration. Therefore, the flanges are the only parts that require special support. This support is given by making the former and back former as shown. The former is made to fit tightly in the section, but that part of the former marked *X* is slightly less in thickness than the overall thickness of the channel. This allows the top plate, when screwed down, to grip the flanges and so prevent puckering. A plain back former can be used, and should be about $\frac{1}{64}$ in. less in thickness than the channel. In making this bend the leverage need not be very short.

Should the bend produced show a hollow back, i.e. a tendency to fall inwards, it may be connected by making the outside edge of the former slightly convex, and the inside edge of the back former concave to counteract the tendency.

FIG. 37.—BAR BENDER CAPABLE OF BENDING MILD-STEEL BARS UP TO $1\frac{1}{2}$ IN. DIAMETER

The bend (*b*) is very simple, as no compression occurs. A plain former with a back former to fit in the mouth of the channel is required (Fig. 38(*b*)).

The thicker-walled channels can even be bent in this direction without a back former with the direct contact of the roller, but this naturally depends on the thickness of wall and the radius of the bend.

The most difficult channel bend is, of course, with the mouth upwards, because not only is it an irregular section, but it is hollow as well, and unless it is thick in proportion to its size, and shallow, the walls will fall inwards under the bending strain.

This type of bend should be loaded with lead or "Cerrobend," or with steel strips. These strips should be made from spring steel about $\frac{1}{16}$ in. thick.

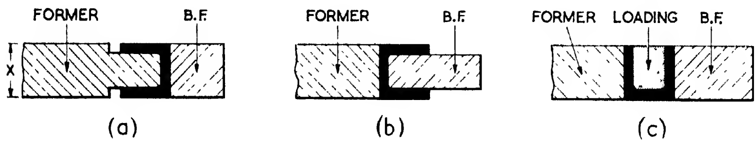


FIG. 38.—BENDS IN CHANNEL SECTION

(*a*) Channel former and back former for bending with the flanges on the inside of the bend.
(*b*) Channel former and back former for bending with the flanges on the outside of the bend.
(*c*) Channel former and back former for bending with the flanges upright. The channel loaded with steel strips or other filling.

Before filling the channel, these should be well greased, and the centre strip left protruding about 2 in. beyond the remainder. This will facilitate removal after bending. This method is not suitable for sharp radius bends, as difficulty will be experienced in removing the strips after bending.

It should be noted that the thinner the section, the more precise should be the fit of the formers.

BENDING TO MEASUREMENT

However good a bend may be, free from kinks and unblemished, it is obviously of no practical use whatever unless it is placed in the exact position needed to form the particular shape that is wanted. It is therefore essential that dead measurement bending can be done easily and speedily. Bending machines are particularly suitable for doing this, and once the principles are understood, it will be realised how easily accurate measurement bending may be obtained.

Light-gauge tubes are bent with overlap formers, i.e. formers which completely overlap the tube for which they are intended. When using this type of former, it will usually be found more convenient to take all measurements from the outside of the tube, which is equivalent to measuring from the outside edge of the overlap former. Presume two right-angled bends are required in opposite directions, with a given distance *G* overall (Fig. 41 (*c*)). It is, in fact, a right-angled double set.

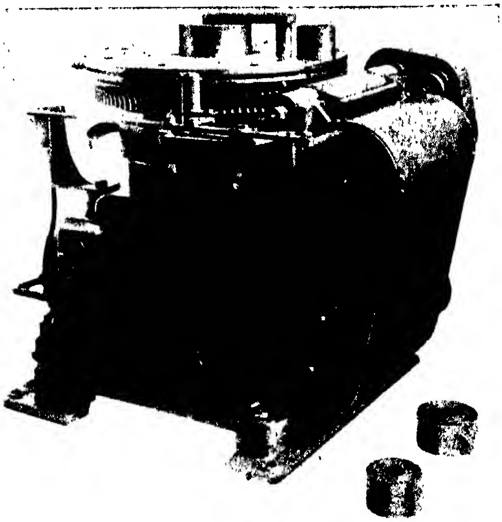


FIG. 39.—2-IN. DIAMETER BAR BENDER ELECTRICALLY DRIVEN

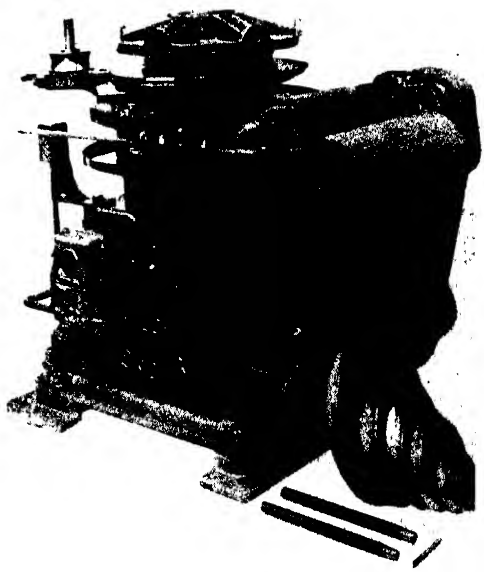


FIG. 40.—POWER-DRIVEN UNIVERSAL BENDER

Measuring for Right-angled Double Set

To obtain measurement *G*, the following procedure should be observed:

1. Mark tube at *H* and *I* (the required measurement).
2. Place a square against mark *H*, and insert the tube in the bender so that the square touches the outer side of the former.
3. Remove the square and bend in the usual way.
4. Repeat for other end.

To obtain any ordinary double set with bends with a given depth of set, a straightedge may be used (Fig. 41 (*b*)), and the bend made as follows:

1. Bend tube to angle required, usually 45°.
2. Place in bender, holding straightedge parallel with *DE* and touching former.
3. Set tube to required measurement at *F*.
4. Bend until parallel with *DE*.

Inside Measurements

If it is desired to work inside measurements, dimensions should be taken from the bottom of the former groove, as shown in Fig. 41 (*a*):

1. Mark the tube at *B* and *C* (the required inside measurement).
2. Place tube in bender, with square against mark *B*, and touching the bottom of the former groove.
3. Remove square and bend in the usual way.
4. Repeat for the other end.

Iron pipes should always be bent to inside measurements, as the formers used are not fully overlap, and the square and straightedge must be placed against the bottom of the former groove.

This applies to all other sections, including angle, Ts, and channels, etc.

STRAIGHTENING BY MACHINE

The term "straightening" is usually applied to the rectification of wire, bars, or tubes which have been damaged sufficiently to prevent them being used

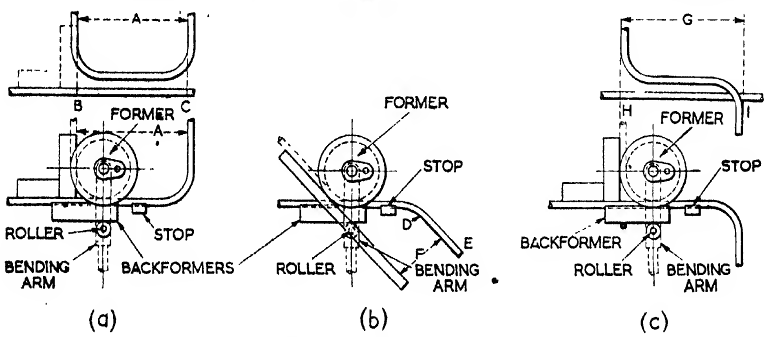


Fig. 41.—Methods of bending to measurement

for their intended purpose. It may be wire that is coiled for transport and requires straightening, or it may be tubes or bars which are slightly bent in places. It is not intended to mean the straightening out of any bend that has been put in a section.

Thus, if a 2-in. tube has been bent to, say, 90° at 8 in. radius, then no machine could remove the bend without spoiling the tube.

A slight rectification of ordinary bends which have been overbent can be done on a bending machine (Fig. 42), but this is not straightening in the accepted sense of the word.

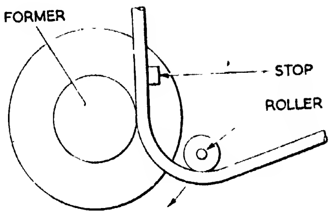


FIG. 42.—A BENDING MACHINE BEING USED TO OPEN A BEND WHICH HAS BEEN BENT TOO FAR

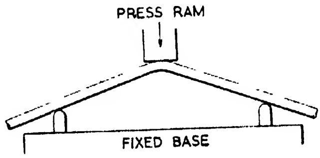


FIG. 43.—PRESS STRAIGHTENING BY PRESSING THE BAR OR TUBE BETWEEN THREE PRESSURE POINTS

Straightening Methods

The usual methods of straightening include the following:

PRESS STRAIGHTENING.—This is the most elementary method, and consists of pressing a bar or tube between three pressure points (Fig. 43). This may be carried out on a press, ram-type bender, or compression bender.

This method is quite efficient, but is dependent on the skill of the operator.

ROLLER STRAIGHTENING.—By this method the section is passed through a series of rollers, which work on the same basic principles as the press method, but the straightening is continuous. The rollers are set to give the maximum deflection as the work enters, and this deflection is lessened on each successive set of rollers (Fig. 45).

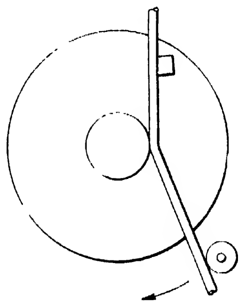


FIG. 44.—PRESS STRAIGHTENING ON A COMPRESSION BENDER

SPINNER STRAIGHTENING.—This method is similar to roller straightening, but the deflecting rollers or pads are mounted in a spinner which revolves round the work. This method is com-

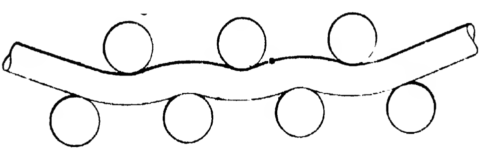


FIG. 45.—ROLLER STRAIGHTENING

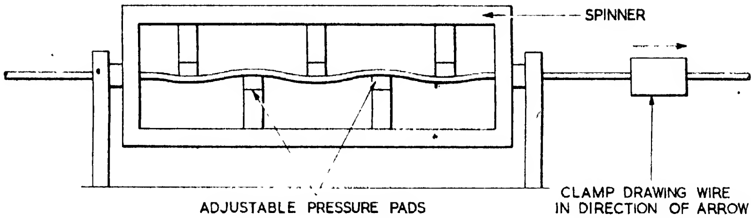


FIG. 46.—SPINNER STRAIGHTENING

monly used for straightening wire up to ¼ in. diameter (Fig. 46). The wire is gripped by a moving clamp, which draws the wire through the rapidly revolving spinner.

STRETCH STRAIGHTENING.—In this method the bar or tube is gripped at each end and is pulled just beyond the elastic limit (Fig. 47).

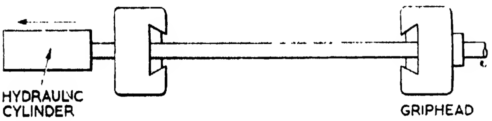


FIG. 47.—STRETCH STRAIGHTENING

ROTARY STRAIGHTENING.—This method is for round material only, and embodies the same basic idea as press straightening, but the process is continuous (Fig. 48).

REQUIREMENTS FOR BENDING MACHINES

Before purchasing any bending machine, it is advisable to consult the manufacturer. The following notes indicate the type of information which should be given:

(1) Section of work to be bent (e.g. tube, angle or bar, etc.).

(2) Size of section or tube.

(3) Gauge or thickness.

(4) Inside radius required in finished bend.

(5) Scale of production required.

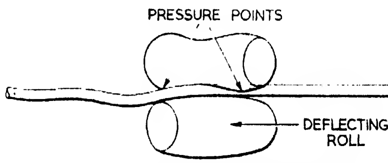


FIG. 48.—ROTARY STRAIGHTENING

It should also be stated whether a single-purpose machine is required or one with a wide range. In the case of the latter, minimum and maximum sizes and radii should be given.

When machines for tube bending are required, it should be stated whether the tubes are bore or O.D. sizes. In the case of bore-sized tubes the gauge is also required.

W. H. K.

METAL SPINNING

THIS process consists of pressing sheet metal into hollow forms in a lathe, by means of various kinds of tools and rollers. The metal receives support on a chuck of suitable contour to mould the desired shape, and before treatment will be either flat or drawn into a shell.

Many articles are only burnished without any formative treatment, while in other cases a drawn object merely has the consequent wrinkles spun down smooth. More than one operation may be necessary in spinning the more difficult examples, because annealing has to be performed after a certain amount of work, to prevent cracking. Materials dealt with comprise steel, copper and its alloys, aluminium, zinc, Britannia metal, and silver. Complementary operations are effected on numerous sorts of spun pieces, including trimming, wiring, and beading, as will be explained.

SPINNING LATHES

These are in some respects simply constructed, but must be able to withstand the great stresses produced in spinning.

THE HAND REST.—Hand tools are manipulated from a simple T-rest, drilled with holes on the top, into any of which a steel pin is inserted to act as a fulcrum for exerting the pressure.

SLIDE REST.—A compound slide rest controls various tools, and there are rests of special form fitted with rollers and other tools constantly performing the same class of operation. A hydraulic type of cross-slide attachment is now supplied by the American Company of F. W. Bliss with their metal-spinning lathes. Fig. 3 shows a Bliss No. 16 lathe with the standard type of cross-slide attachment, whilst Fig. 4 shows the lathe fitted with the hydraulic type.

DRIVING THE LATHE.—Belt drive alone is sufficient for a good many lathes, but heavy ones require back gear.

TAILSTOCK.—The poppets or tailstocks are either simple, with plain or ball-bearing point centre, or of special type, to manipulate the pads which keep the work against the chuck.

Lathes in Action

Fig. 1 represents a lathe by the E. W. Bliss Company, having headstock spindles running in roller and ball bearings. The tailstocks possess lever-actuated spindles and lock for rapid application. The operations in progress are with sliding rests, the first lathe spinning only, the second trimming edges and bending them over.

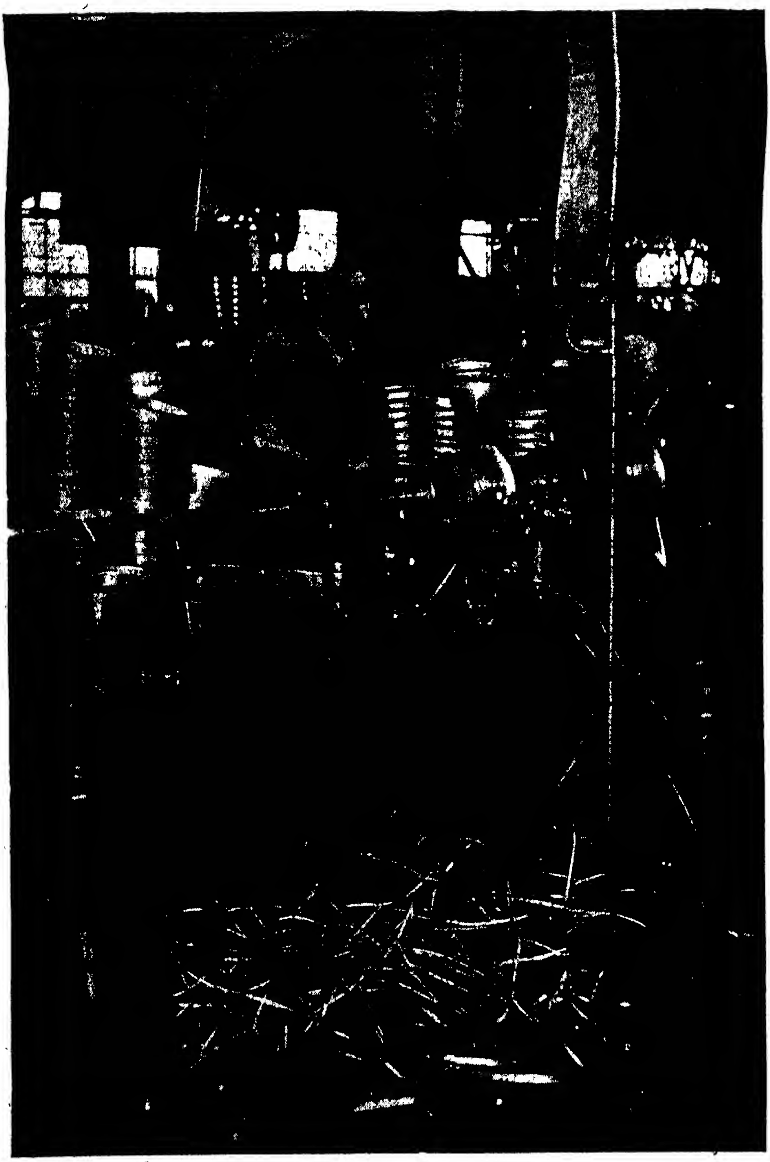


FIG. 1.—OPERATING TRIMMING AND BEADING TOOLS ON ALUMINIUM SAUCEPAN
(*E. W. Bliss Company*)

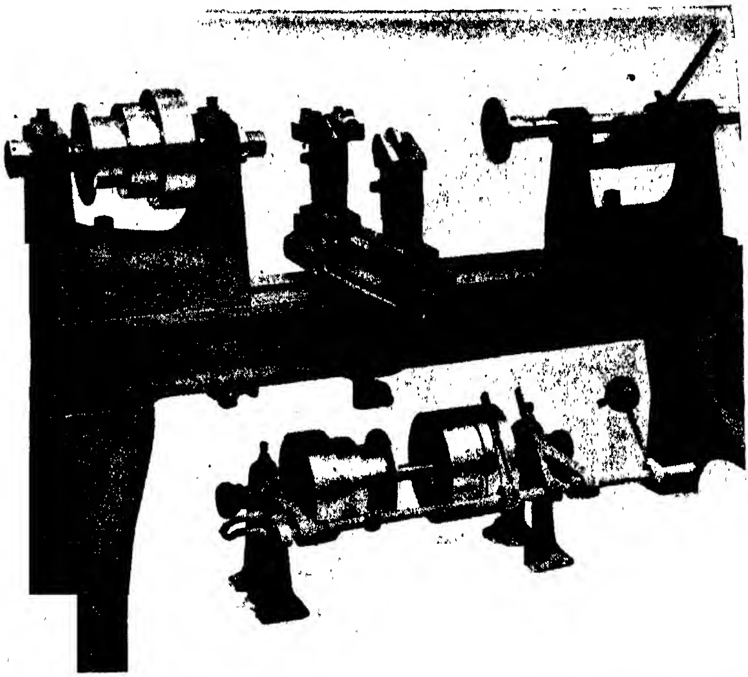


FIG. 2.—SPINNING LATHE ADAPTED FOR TRIMMING AND BEADING WITH LEVER-OPERATED SLIDE
(*Charles Taylor* (*Birmingham*), *Ltd.*)

Specimens of spun articles may be seen in Fig. 5, these being among the more difficult subjects, involving the use of special devices.

The lathe in Fig. 2, by Charles Taylor (Birmingham), Ltd., takes stampings and trims off the uneven edges, then curls them over. The lever-operated rest carries front and rear tools, and the tailstock has a spindle quickly slid and locked by the lever.

CHUCKS

Simple Chucks

The best wood for this purpose, if available, is lignum vitæ; but hardwood is also suitable for chucks, and brass or iron for long-continued service.

Fitting Wood Chucks to Lathe

Large wood chucks go direct on the threaded spindle nose, smaller sizes on a taper screw chuck (Fig. 6) of coarse pitch, which fits either on or inside the spindle nose (see *A* and *B*). *C* is a simple chuck, and the work is spun upon it.

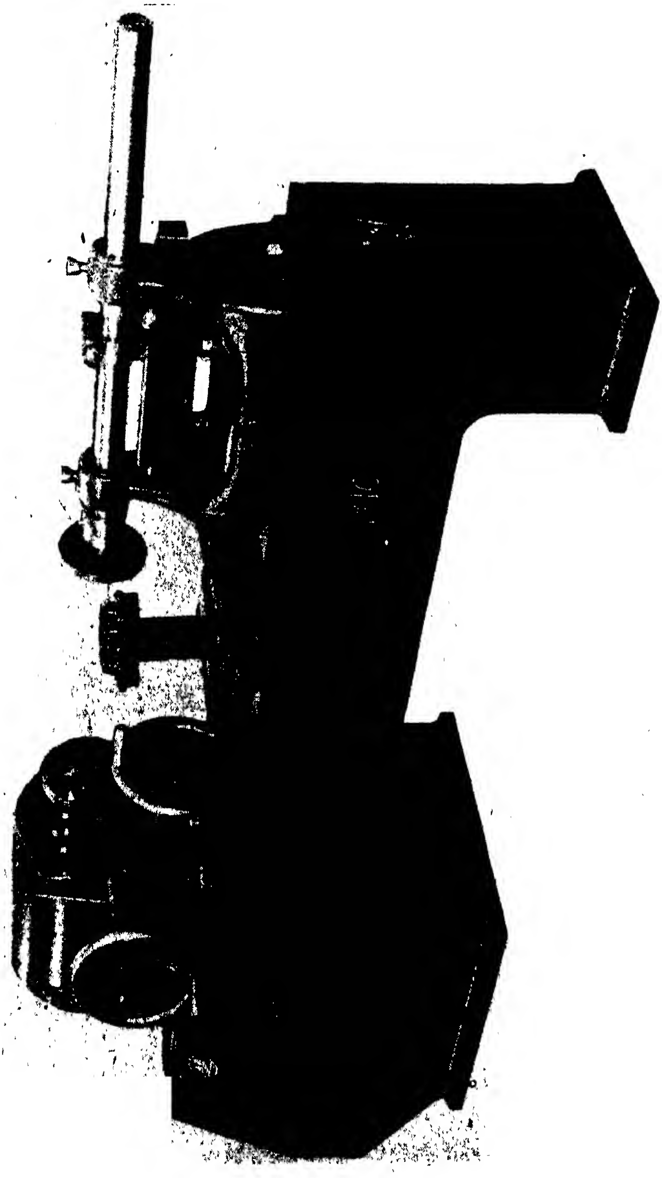


Fig. 3.—A Bliss No. 16 metal-spinning lathe fitted with standard-type cross-slide attachment
(*E. W. Bliss Company*)

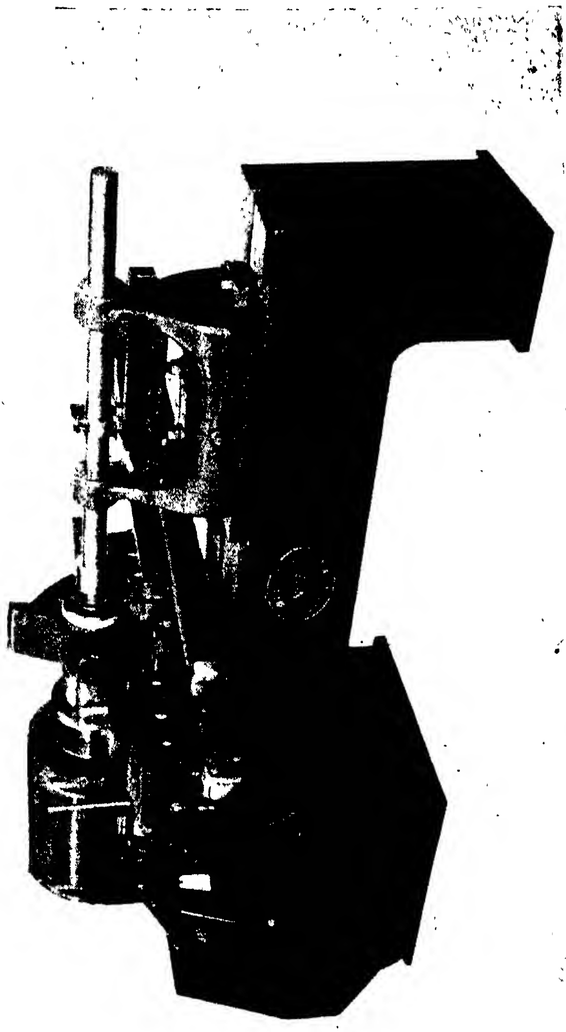


FIG. 4.—A BLISS NO. 16 METAL-SPINNING LATHE, FITTED WITH HYDRAULIC TYPE CROSS-SLIDE ATTACHMENT
(*E. W. Bliss Company*)

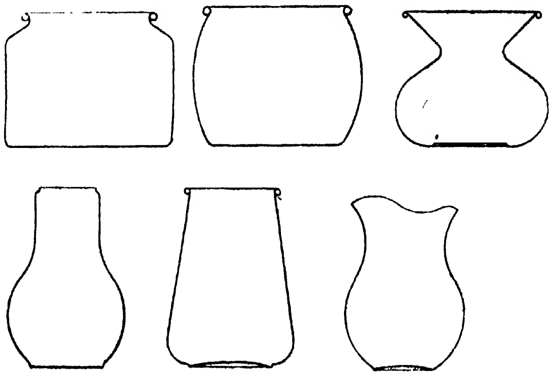


FIG. 5.—METAL-SPINNING WORK
Specimens of articles spun to shape from straight shells.

Oval Chuck

For spinning elliptical work, such as trays, pans, bowls, brush backs, knobs, and so on, what is called an oval chuck has a threaded nose on which the work-holding chuck has to be screwed. The nose being made in one with a slide, this is caused to move in an elliptical orbit through the action of a former ring attached to the front of the headstock. Lateral adjustment to the ring varies the throw. The die on which spinning is done can also be turned up by means of the oval chuck and a slide rest with tool set exactly to centre height.

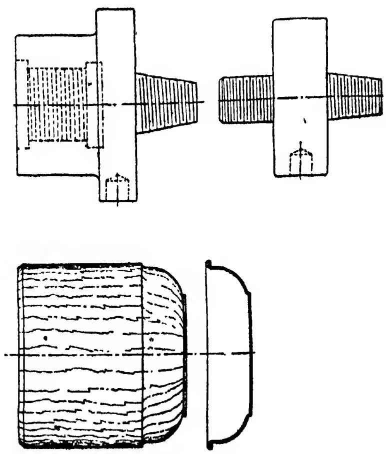


FIG. 6.—CHUCKS FOR METAL SPINNING
A and *B*, taper screw chucks for Taylor spinning lathe. *A* is fitted on spindle nose and smaller chuck *B* is fitted inside spindle. *C*, wood chuck with example of work which is spun on it.

Working with the Taylor Oval Chuck

Fig. 7 illustrates the Charles Taylor chuck. There must be no backlash in the various parts, or a series of flats will be found around the periphery of the work. For accurate and ready adjustment, dowel holes and dowels are provided, as lettered on the drawing. The sequence goes as follows:

Set the back plate carrying the former ring *A* central with lathe spindle, and insert dowel peg 1.

Release the four screws *B*, ease back the adjusting screws *C*, and insert dowels 2. Tighten screws *C* until they touch cross-bars *D*.

Insert dowels 3.

Take up any play between the former ring and the gunmetal rubbers *E* by means of rods *F*.

Remove the four dowels 2,

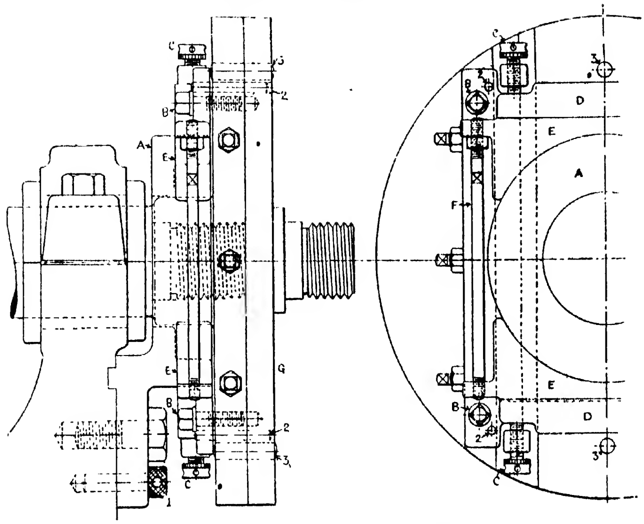


FIG. 7.—TAYLOR OVAL CHUCK.
By means of this chuck elliptical shapes are spun

turn all four screws *C* through the same number of divisions marked on their heads, thus adjusting the cross-bars *D* parallel and a working fit on the gun-metal rubbers.

Tighten up screws *B*.

Adjust the front slide *G* by means of the gibs and screws.

Remove dowels 3.

Remove dowel 1, and adjust the former ring across to produce the ellipse required. Frequent oiling of the parts is essential.

Loose Poppet for holding Work in Oval Chuck

In order to hold work in an oval chuck, the style of loose poppet outlined in Fig. 8 is employed; it has lever and link to put on the pressure, and the contact pad seen close to the faceplate goes on a spring-fitted rod having ball joints giving freedom of movement.

SPINNING OPERATIONS

Simple Spinning

Ordinary spinning may be seen in Fig. 9, with spinning and burnishing roll manœuvred by slide rest, the shell being held up by the tailstock pad. The shape of the spinning roll may be modified to suit requirements. The amount that the piece can be changed in one operation is limited by the degree that the metal will stretch without annealing.

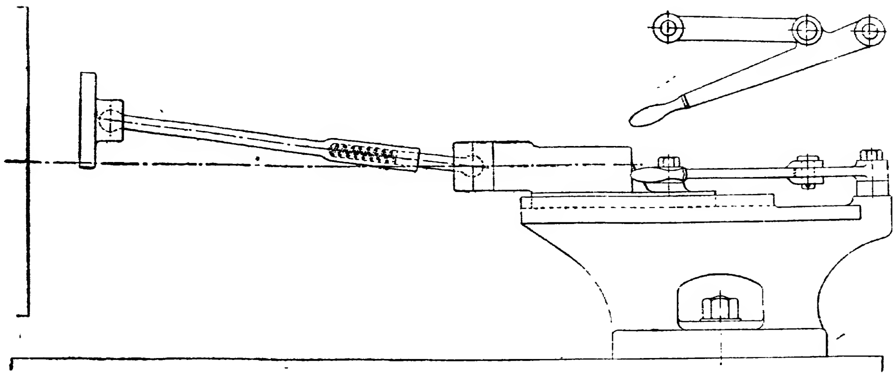


FIG. 8.—SPECIAL TYPE OF TAILSTOCK OR USE WITH OVAL CHUCK

Note the spring-pressure rod with ball joints.

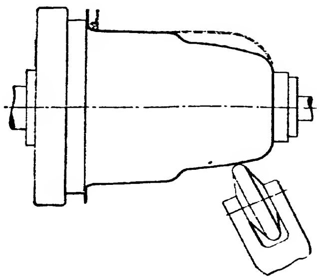
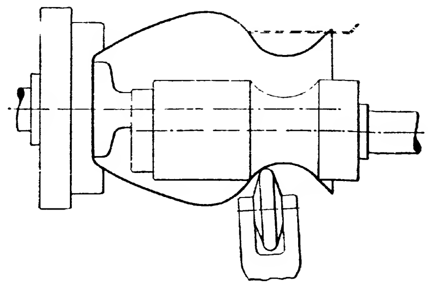


FIG. 9 (*left*).—ORDINARY SPINNER

With roller controlled by slide rest still being spun to contour of chuck. Original outline shown dotted.

FIG. 10 (*right*).—A MORE DIFFICULT OPERATION

The neck is supported during spinning by means of a formed roll, which is offset by the tailstock.



Offset Spinning

More difficult handling occurs in Fig. 10, where the problem of the contracted neck is met by utilising an offset tailstock spindle with formed roll, against which the contour is spun with the slide-rest roller as shown. The tailstock has a cross-sliding adjustment to set the roll out, and retire it after completion of the necking. The bulging of the lower part of the shell has been done at a previous operation.

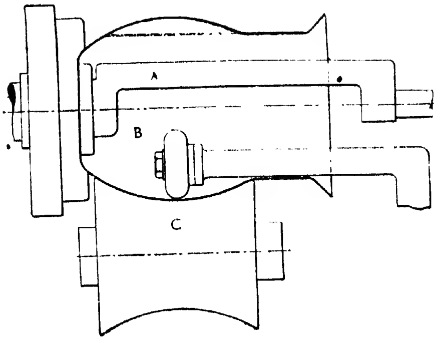


FIG. 11.—BULGING FROM THE INSIDE
Roller works on inside while outside of shell is supported against a formed roll which controls contour of shell.

Spinning from Inside

A method of bulging with a roller pressing from the interior is evident in Fig. 11, the dotted line showing the shape before this has been accomplished. *A* is the tailstock pressure arm holding the work into the chuck, *B* the spinning roll carried on an extension arm from the regular compound rest, by means of which it is manipulated. Formed roll *C*, against which the spinning roller shapes the metal, is mounted on a separate post on the bed of the lathe. This roll is necessary to obtain good results in steel; but for aluminium, a cam on the bed which can be followed by a roll or indicator on the cross slide may be used. Figs. 9–11 are from the practice of the E. W. Bliss Company.

Attachment for Forming Necks

A method originated by Messrs. Taylor & Challen, Ltd., for use on their spinning lathes (Fig. 12) can be employed to spin necks or close in stampings after leaving drawing presses. The stamping is slipped on the roller *A*, revolving on an eccentric bush *B* with which adjustment can be made for pressure of rolling. Clip *C* fixes *B* on its spindle, while the latter goes in a holder secured to the loose head spindle. After slipping the stamping on the roller, the spindle is driven forward by hand or foot action, thus gripping the piece into the revolving chuck by the pallet plate *D*. Next the spinning roll *E* is operated by the compound rest, until the shape has been spun, the tailstock spindle withdrawn, and piece removed, all without stopping the lathe. Roller *A* must be shaped according to how much the metal will stand per operation, two rollers being required for the example illustrated.

Trimming and Beading

These processes are sometimes performed on the same lathe as the spinning,

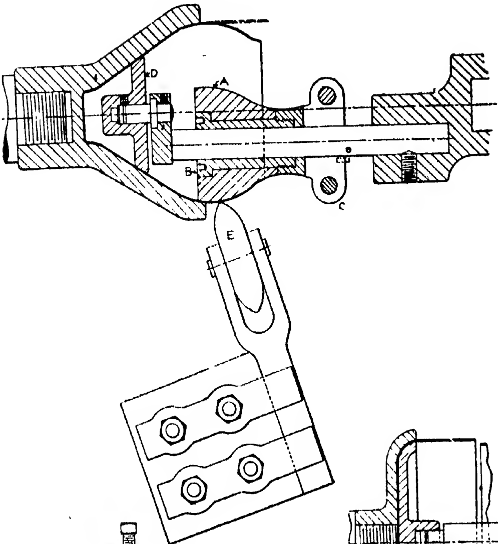
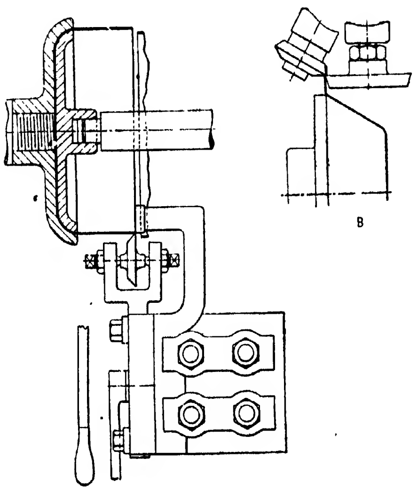


FIG. 12.—COMBINED PRESSURE PALLET AND FORMING ROLLER MANIPULATED FROM LOOSE HEAD



A

FIG. 14.—METHODS OF TRIMMING

A, Lever-actuated rest trimming a cup shape after leaving the drawing press. *B*, Trimming by means of bevelled cutters, which are moved to or from each other.

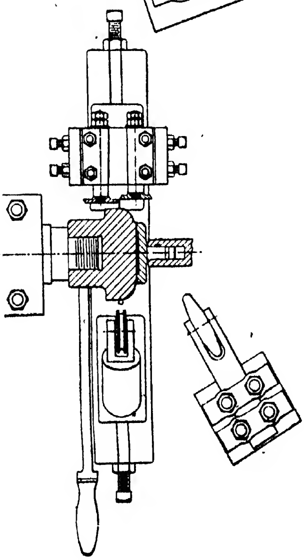


FIG. 13.—SPINNING, TRIMMING, AND BEADING ON ONE LATHE

Spinning roller is on slide rest. Trimming cutters and beading roller are on cross slide.

or one operator may spin, and pass the article on to another worker, a single long bed often taking two sets of heads and rests.

The combined outfit (Taylor & Challen, Ltd.), shown in Fig. 13, mounts the spinning roller on slide rest to the right, and the trimming cutters, and beading (also termed curling and wiring) rolling on a cross slide fed to and fro by the lever at the left. Stop screws at each end of the cross slide determine the limit of stroke.

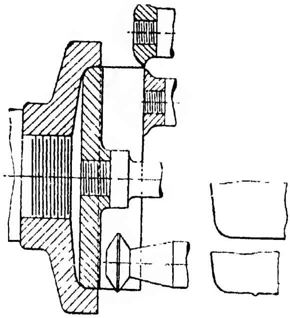


FIG. 15.—TRIMMING AND MARKING A COVER IN A SPECIAL LATHE

Detail on right shows subject before and after treatment.

Trimming Only

Systems of trimming by the same firm may be noted in Fig. 14, *A* dealing with cylinders and cups up to 16 I.W.G., after coming from the drawing press; the top portion of the compound slide rest is shown, and the lever effects the operation. The other scheme *B*, comprises a rest with lever mechanism to move the bevelled cutters simultaneously to or from each other.

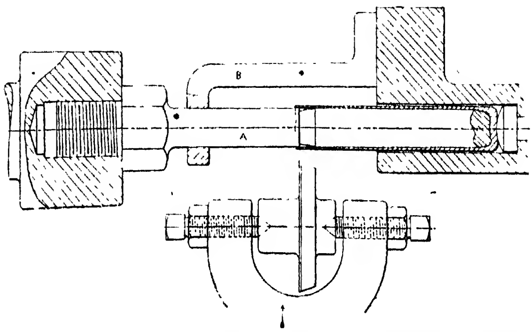


FIG. 16.—ACTION OF AUTOMATIC LATHE FOR TRIMMING CARTRIDGE CASES BY CIRCULAR CUTTER

Case is pushed on to mandrel *A*, sheared to length, then stripped off by return stroke of *B*.

Trimming and Marking

Covers for saucepans, oil drums, etc., are trimmed and marked, preparatory to the

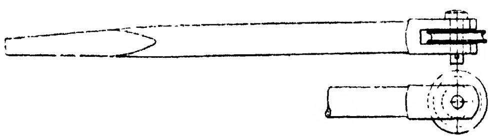


FIG. 17.—TURNING OVER OR WIRING TOOL

With this tool, edges can be finished with a neat curl.

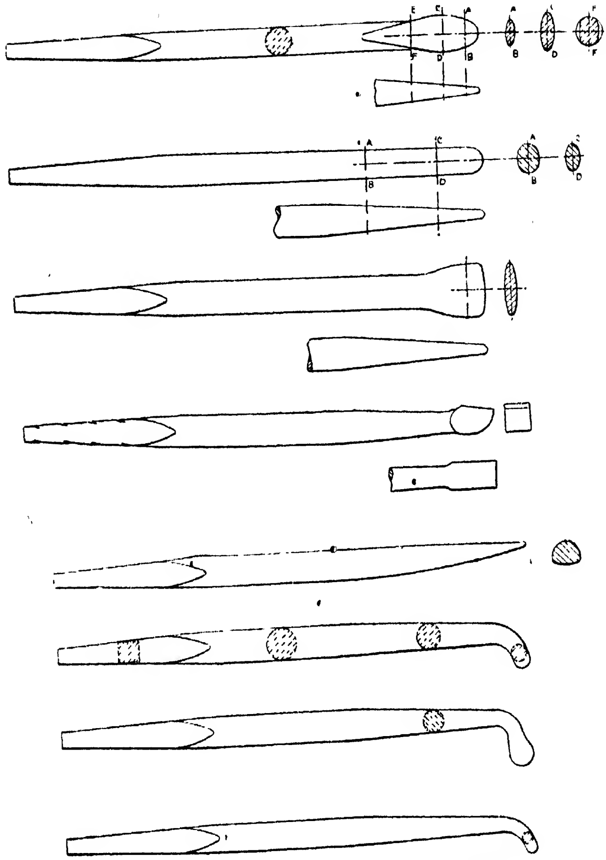


FIG. 18.—SET OF SPINNING TOOLS SHOWN IN DIAGRAMMATIC FORM

These are fitted in wooden handles and manipulated on a T-rest in order to spin and burnish various contours. (*Charles Taylor (Birmingham), Ltd.*)

flanging process, by the set-up in Fig. 15, also on a lathe of the foregoing makers. A lever moves the trimming cutters together, and another one feeds the marking roller. Toggle mechanism actuated by pedal grips the stamping.

Automatic Trimming Lathe

Fig. 16 gives a plan of the mode of action of an automatic Taylor & Challen lathe, which takes cartridge cases or like objects from a chute by means of a

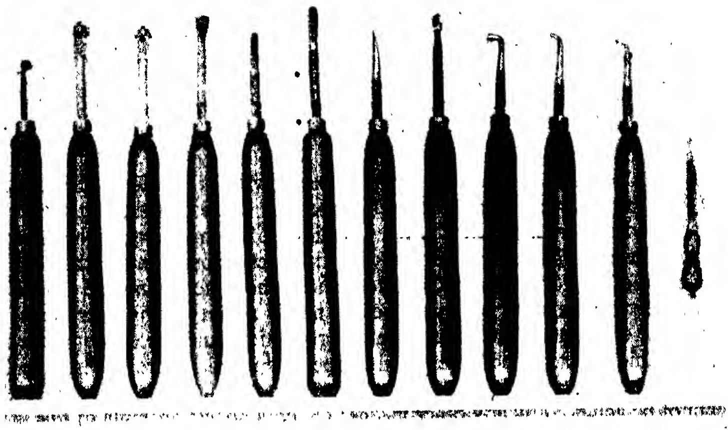


FIG. 19.—SPINNING TOOLS AS SHOWN IN FIG. 18
(*Charles Taylor (Birmingham), Ltd*)

slide, threads them on to a revolving mandrel *A*, ready for the advance of the circular cutter shown. The return movement of the slide causes extractor *B* to strip the trimmed case off the mandrel.

Spinner's Hand Tools

Rather curious tools are used with the hand rest and fulcrum pin previously mentioned. Figs. 18 and 19 show a set furnished by Charles Taylor (Birmingham), Ltd. The first two drawings in Fig. 18 are of tools with burnished ends, applied variously at the discretion of the operator to spin and burnish straight portions, external and internal curves, bends, corners, etc. These tools are a foot long over all, and go in ordinary wooden handles 15 in. long. Fig. 17 is the roller tool for turning over or wiring, holding a roller of appropriate radius to suit all requirements.

POWDER METALLURGY

A NATURAL question for any engineer is, what is powder metallurgy and what can it do to merit the attention and interest of the engineer?

Powder metallurgy is the technique of forming solid objects from metal powders. Its advantages are the extremely close control that can be exercised over properties, size, and tolerances, the almost complete absence of the high percentage of waste involved in nearly all machining operations, the high rate of output obtainable by mass production, and the economies which the technique makes possible when properly applied. There is also the fact that by powder metallurgy it is possible to obtain physical properties that cannot be achieved by any other means; the commonest example of this is the porous bearing which finds application in machinery all over the world. The hard metal, or carbide machine tool, is perhaps of greater importance to engineering today than the porous bearing, and is 100 per cent. a powder metallurgical product. Obviously the word that commands attention and raises curiosity is "powder."

How does powder differ from matter in larger pieces? Almost wholly in that it is finely particulate and offers very much more surface to either chemical or physical action than matter in larger particles or pieces. Think of a cube of metal having faces an inch square. Suppose that cube of metal reduced to powder can just pass a 300-mesh sieve; that powder will now have a surface of about 300,000 sq. in., that is, an increase from 6 sq. in., the surface offered by the original inch cube, to 50,000 times that surface. In the daily practice of powder, metallurgy powders of this fineness, i.e. that will pass a 300 mesh, are in common use, but are by no means restricted to that particular size.

It is usual to have a mixture of particle sizes so that the finer particles can help to fill the voids or empty spaces between the larger particles, and so help in producing a more solid and less porous article or compact when pressed. Such a mixture might well be specified to contain no powder retained on a 100-mesh sieve, 25 per cent. to be retained on a 200-mesh sieve, 25 per cent. on a 300-mesh sieve, and 50 per cent. to pass through a 300-mesh sieve. Such a sieve analysis would be expressed as follows:

On 100 mesh . . .	Nil
On 200 mesh . . .	25 per cent.
On 300 mesh . . .	25 per cent.
Pass 300 mesh . . .	50 per cent.

In addition to particle size, and also particle shape, the density of the powder is important. That is not the density or specific gravity of the solid

metal or of an individual particle, but is the weight of a unit volume of the powder loosely packed. The unit volume is usually 1 c.c. and the weight is expressed in grammes; thus we obtain what is called the apparent density or loading weight, and we express it as grm./c.c. The important rôle of the apparent density will be explained in discussing the die fill before pressing and also what is called "compression ratio." Another property is the flow-factor, also of importance in checking and maintaining even quality of powders over periods of operation.

PREPARATION OF POWDERS

The powder metallurgist does not usually prepare his own powders; that is done generally by firms specialising in powder production. They use a variety of methods, each suited to providing a powder having special characteristics and particularly suited either by particle shape and size, and/or physical properties to produce a chosen result. Many methods are in use, and may be briefly mentioned. Mechanical disintegration by grinding, machining, or milling is used with metals which are brittle and which can be powdered by percussion; such powders are usually of angular particle shape, and may be hard although brittle; they find application when hard in the production of brake blocks for heavy duty and for some friction clutches.

Atomised Powders.—Atomised metal powders are of increasing importance today, and are produced in large quantities. The production consists in submitting a stream or jet of molten metal to a powerful jet of air, gas, steam or water, so that it is atomised in much the same way as perfume is atomised by an air-stream. Very many commercial metals and alloys are reduced to powder form in this manner, especially aluminium, cadmium, copper, lead, tin, and zinc, and the process is especially useful for alloy powders, of which the more important are the brasses, bronzes, solders, and many others. Atomised metal powders usually have a spherical or tear-shaped form.

"Reduced" Powders.—Powders reduced from oxide are widely used: of these by far the most important is iron. Copper was at one time used in large quantities as powder reduced from oxide, but both atomised and electrolytic powders have now largely replaced the reduced forms. Reduction is a chemical process, and is the chief method employed to produce the tungsten and titanium powders used in the hard-metal industry in the form of carbides. It is also used to produce cobalt, which provides, sometimes with nickel, the cementing liquid phase in the actual carbide compacts providing the hard-metal cutting tool.

These varied methods of production impress their own characteristics on the powders produced by them, so that notable differences are found in hardness, abrasive, or die-wearing properties. These variables are useful to the powder metallurgist, for they offer him wider opportunity for controlling the properties of the components he desires to produce. The actual processes of powder metallurgy at their simplest are two only, that is, pressing and sintering. For the simplest products these two operations are all that are necessary, and the finished product issues from the sintering furnace in a bright, ready-to-use

FIG. 1.—POWDER METALLURGY PRESS
This illustration shows the production of bronze porous bearings.
(*Sintered Products, Ltd.*)

condition. Where fine tolerances are required, there may arise the necessity for a coining operation, usually carried out in the cold after sintering, but that is not the rule.

PRESSING OF POWDERS

The presses used in powder metallurgy are derived from the tableting press which produces medicinal tablets. They are largely automatic in operation, and consist of the die which confers the required shape on the metal powder when compacted, punches, usually two in number, an upper descending punch engaging the die and pressing the powder contained in it downward, and a lower punch pressing the powder upward in the die, and after a predetermined "dwell" continuing its upward movement so as to expel the compressed piece from the die.

Cycle of Operation.—In Fig. 1 a press is seen producing bronze porous bearings; the upper punch has returned to its highest point and the lower punch has just ejected the pressed bearing from the die; in a fraction of a second the operator will move the bearing away and the cycle of operations will recommence. They comprise filling the die, removal of excess metal powder by a mechanical arm sweeping across the top of the die, descent and ascent respectively of the upper and lower punches, dwell at maximum pressure, rise of punches and expelling of compact, usually called, when in this unsintered state, the green compact, and removal of same. Presses for automatic operation with single or multiple dies are usually restricted to a total pressure of not more than 30 tons per square inch, and to objects of small size, where higher pressures are used and larger parts are produced, hydraulic presses are essential.

The pressure necessary for any particular operation depends upon the properties of the powder, its hardness, its compressibility, and its capacity for interlocking. It is essential to remember that a powder in a die will not flow under the pressures normally applied; that means it cannot flow round a re-entrant angle, and conditions that are met with in liquids where pressure on walls will be identical over all surfaces never arise in pressing metal powders. In metal powders there is friction between individual particles of metal, between punches and powder, and between powder and the walls of the die; thus the deformation of a mass of metal powder does not follow simple mechanical laws.

Usually there is an optimum pressure for any one particular metal or alloy

powder. Beyond this optimum, increasing pressure gives no increase in physical properties. Application of pressure should be even and simultaneous above and below. Rate of application is important; it should not be too rapid, or too much air may be entrapped, causing lamination and other troubles during sintering.

Die Design

Die design is important. It must take into consideration the nature of the powder or powders to be used; the rate of abrasion or wear will determine the material from which the die is constructed. This may be of alloy steel of the molybdenum or vanadium types, or the air-hardening manganese-chromium-molybdenum alloy steels, which show little dimensional change on heating. There is a growing tendency to provide die lining of highly polished carbide, which not only resists abrasion and wear, but can also be heated for hot pressing operations that offer special advantages with many materials.

Die design must take into consideration the behaviour of the compact during sintering. It must allow for any shrinkage or swelling that may occur, and be designed so that the final cooled and sintered compact conforms to the tolerances in dimensions called for by the specification. Another factor influencing die design is the compression ratio, that is, the ratio between the volume of a powder in the die before and after pressing. This ratio for many of the commoner metals and alloys is usually of the order of 3 to 1. That means that a 3-in. column of unpressed powder in the die will be reduced to a 1-in. column after pressing. This compression ratio naturally influences the density and the porosity of the finished pressing. It is in turn influenced by the hardness or softness of the powder, by its particle shape, and above all by its apparent or loading density.

Powder Control Factors

The control of the powder and the assuring that it is maintained of even specification is obtained by strict adherence to the particle-size specification as given by mesh analysis, adherence to constant loading weight, which depends upon particle-size distribution expressed as mesh analysis, and by the flow-factor of the powder. This is determined by finding the seconds required for a weighed quantity, usually 100 grm., to flow through a carefully machined cylindrical orifice of a metal cone having an internal angle of 60°. The pressures actually exerted on the powder in the die vary according to the hardness of the metal being pressed, from 5 to 10 tons per square inch for soft metals like lead to 50 or more tons in the case of iron or steel.

Sintering

The cold pressing and production of the green compact is followed by the sintering, which usually is a continuous process whereby the green compact is subjected to a temperature usually well below the melting-point of the major constituents. Examples are bronze for porous bronze bearings where the sintering temperature ranges from 750° to 850° C., or iron or steel compacts where the range may be 1,000° C. and upward. Sintering is almost invariably

FIG. 2.—THE SINTERING FURNACE
Showing the operator feeding the loading end of a typical furnace.
(*Sintered Products, Ltd.*)

carried out in a protective or a reducing atmosphere. Burnt or partially burnt coal gas supplies a protective atmosphere, and the ratio of carbon dioxide to carbon monoxide can be varied at will.

For a reducing atmosphere the most popular is hydrogen either produced electrolytically or by the cracking of ammonia gas. The loading end of a typical sintering furnace is seen in Fig. 2.

The Sintering Furnace

The sintering furnace derives from the bright brazing furnace. It usually has a travelling bed upon which the compacts are placed, or they travel on suitable trays. In some cases the compacts are packed in suitable material to obviate loss of either carbon or some other volatile constituent such as zinc during the sintering. It need hardly be said that sintering is a delicate operation, and that factors, such as temperature, pressure, time of sintering, can all affect the final result. In general, physical properties, such as compressive and tensile strength, increase with the rising density of the compact up to the point where grain growth becomes rapid; beyond that point there may be a decrease or an increase dependent on shrinkage and grain growth. Elongation increases more slowly than the other physical properties. A reasonable amount of control is possible, and hence powder metallurgy can work to fairly close tolerances.

In small components, such as small gears, cams, porous bearings, etc., the limits on I.D. and O.D. are about 0·001 in. for parts about an inch in diameter, and of 0·005 in. in lengths up to several inches. Where very close tolerances are

required, a coining or second pressing in special dies is used either cold, or warm after an annealing. By this means tolerances of one or two ten-thousandths of an inch can be held.

USES OF POWDER METALLURGY

Among the important advantages of powder metallurgy are the production of materials having properties obtainable in no other way, e.g. metals of known and controlled porosity; compounds and forms so hard that they cannot be fabricated by any other procedure, e.g. hard metals; ductile metals, such as titanium, zirconium, even platinum that can only be produced by commencing with a pure reduced powder, hot pressing to a porous block, and then swaging to a ductile billet. Next, there is speed of production, where small articles can be turned out at as high a rate as 30,000 pieces an hour, even components having surfaces of 10–12 sq. in. and requiring a pressure of 30 tons per square inch have been produced at a rate of 1,200 per hour.

On the other side powder metallurgy cannot compete with either gravity, pressure, or die-casting in cheap metals, nor with cheap pressings, and there are many complex forms that are more economically produced by casting, extruding, and then machining. It has to be pointed out, however, that the last few years has seen a very big advance, not only in the class and quality as well as size of the components that powder metallurgy can successfully produce, but also in production of parts, especially of alloy steels and similar materials, having properties well above those obtainable in other materials, and produced at a saving of from 20 to 30 per cent. on the costs of the older and not-so-good article.

FIG. 3.—BEARINGS MADE FROM LOW-CARBON STEEL
(*Powder Metallurgy, Ltd.*)

Applications

Taking first those products only possible by using powder metallurgy, we have two principal groups of those with a planned porosity.

Bearings.—First the earlier and very well known porous-bearing materials, of which the best-known are the self-lubricating bearings, that are the oldest and most widely known product of powder metallurgy. These components, ranging in size from parts weighing several thousand to the pound avoirdupois to others weighing a couple of hundred pounds apiece, are now familiar both in bronze and in iron, the latter tending to replace bronze for the heavier items. The smaller sizes are all

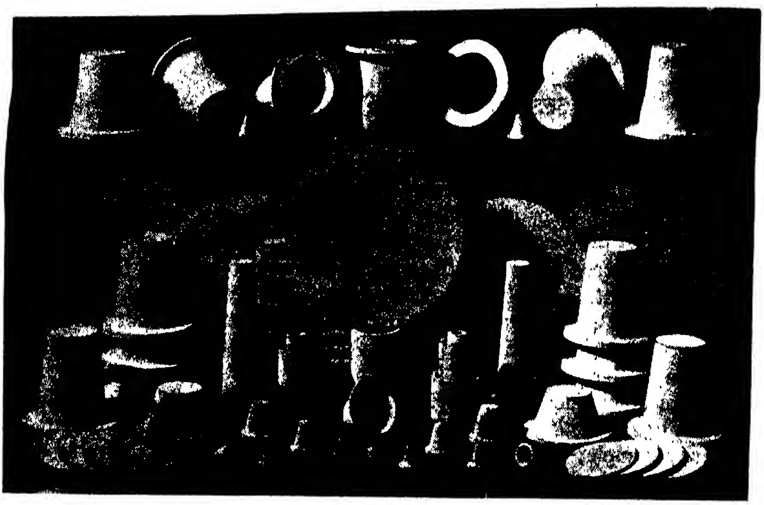


FIG. 4.—GROUP OF SINTERED POROUS ARTICLES

In the production of these pieces, carefully graded spherical-shaped particles of metal or alloy are sintered to produce a wide range of filtering materials. (*Sintered Products, Ltd.*)

of the self-lubricating type, which are oil impregnated by immersion in a warm oil bath under vacuum. Their porosity averages 30 per cent. of their total volume, thus providing an excellent reservoir of oil. High-duty porous bearings are generally of iron, or even alloy steel. They have much greater resistance to compression and have a porosity of the order of 15 per cent. of their volume. Examples are shown in Fig. 3 of bearings made from low-carbon steel powder.

A valuable development is the steel-backed bearing, in which the bearing surface is a layer of copper-lead. This is not an alloy, but a suspension of lead in copper; the lead ranges from 30 to 40 per cent., and such suspensions can only be produced successfully by a process of atomising the metals while being mixed in a fully molten state. These bearings are now produced in England in large and increasing quantities.

Filtering Media.—The second group of porous articles are those in which the use of carefully graded spherical-shaped particles of metal or alloy are sintered in such a manner as to produce a wide range of filtering materials having a very closely controlled porosity ranging from 10 to 60 per cent. and an equally closely controlled pore size ranging from 1 to 200 microns (1 micron = 0·001 mm.). They have many applications in the filtering and mixing of gases and liquids, and have given most valuable service in the chemical and food industries, in the filtration of water, oils, including fuel oil, and other fields. Their diversity in shape and size is well seen in the groups illustrated in Fig. 4.

Electrical Contacts.—Among products of powder metallurgy in which

porosity plays a secondary part can be considered the very wide range of contact pieces for switchgear and similar uses in the electrical industry. Such contact pieces have to combine high resistance to heat with high conductivity for electric currents. To this end combinations of metallic molybdenum or tungsten, both of very high melting-point, are combined with copper or silver, both having high conductivity, in such a manner that make and break of contact occurs at highly refractory faces, whereas the high-conductivity material provides the channel for the current once contact has been made.

Cementation Products.—A very valuable technique has been developed recently to which the name cementation or impregnation is given. It consists in producing an iron or steel compact in the usual way, and then filling the voids or porosities with a metal of lower melting-point, such as copper. This has given compacts that have no brittle phase and possess tensile strengths well above those obtainable with iron powder alone. Tensiles of from 29 to 31 tons per square inch have been obtained. Such iron-copper combinations can be heat treated by quenching and tempering, they can be carburised, they take chromium or nickel plating perfectly, and they can be brazed together without the necessity for adding any brazing metal. They have exceptional machinability, and are a development worthy of the engineer's interest.

Magnets.—Another field for non-porous materials is the provision of magnets and magnetic material of outstanding quality. Of much greater importance is the tremendous field of hard metals as they are called. Of these the most important are the tungsten-titanium carbides. Here a cementing metal is used which provides a liquid phase during the final sintering, and so binds the fine-particled hard-metal carbide into a solid mass with a hardness only little short of the hardness of the diamond. The use of a liquid phase, usually cobalt or nickel, was necessary in the first place to overcome the extreme brittleness of the carbides alone. Now it has moved a step farther, and so the brittleness of the carbide mass has been reduced to the point where it is capable of taking the place of steel in the rotary percussive drills used for sinking boreholes in prospecting underground.

Nickel-steel Tools.—Yet another important development has been the production of parts, especially for tools, in sintered nickel steel. Here a modified hot pressing method is used, and parts, such as tangential dieheads, have been produced having an ultimate strength of 28–30 tons per square inch, with an elongation of 8 per cent. These materials can be heat treated and hardened up so that a file will not touch them. Some of the most recent figures obtained by quenching and tempering the result of hot pressing and sintering some American steels, in particular S.A.E. 1095, gave hardness equal to 39 Rockwell C and tensiles varying from 70 to 80 tons per square inch.

A process capable of results such as these, capable too of such versatility as is shown by the recital of its many products, cannot be over estimated. Power metallurgy has inherent qualities that will increase its importance year by year until it is finally of at least equal importance with classical metallurgy.

H. W. G.

MAINTENANCE OF TUNGSTEN-CARBIDE DIES

DIES made from cemented tungsten carbide have remarkably wide resistance qualities. From this, however, it must not be assumed that these components require no attention or maintenance.

In order to obtain uniformly satisfactory results from these dies, and to ensure maximum life, periodical examination and, if necessary, servicing, should be carried out. The following is a list of the equipment and expendable stores recommended by Protolite, Ltd., for the Die Maintenance Department:

MACHINES

Polishing head, with some form of tailstock attachment. Speed 1,500–2,000 revolutions per minute.

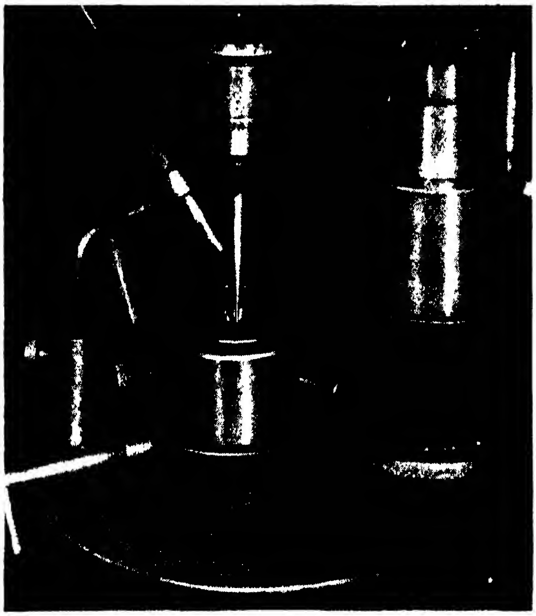


FIG. 1.—RIPPING OR REGRINDING A WIRE-DRAWING DIE
Bore sizes 0·100–0·500 in. (*Protolite, Ltd.*)

Lathe. Speed up to 1,000 revolutions per minute.

Flexible shaft lapping machine.

Large carbide-die ripping machine.

Small carbide-die ripping machine.

Lapping machine for shaped dies.

Hand grinder and hand-lapping device.

ABRASIVES

200-mesh diamond powder (British Standard Specification).

400-mesh diamond powder (British Standard Specification).

Fine diamond powder (0–2 microns).

Diamond pieces (1-carat size. Boant).

200-mesh silicon carbide, or boron carbide.

400-mesh silicon carbide, or boron carbide.

LAPS AND NEEDLES, ETC.

Mild-steel or low-carbon steel rod. Size to suit work.

Brass rod. Size to suit work.

Orange or peg-wood sticks.

Dowel-wood or hardwood sticks.

Soft deal or pine sticks.

Tissue paper and cotton-wool.

Olive oil or light spindle oil.

Beeswax.

Felt buffing wheels, medium and hard.

Magnifying glasses, ×5, ×10, ×20.

The above list of equipment and expendable stores will suffice all ordinary requirements.

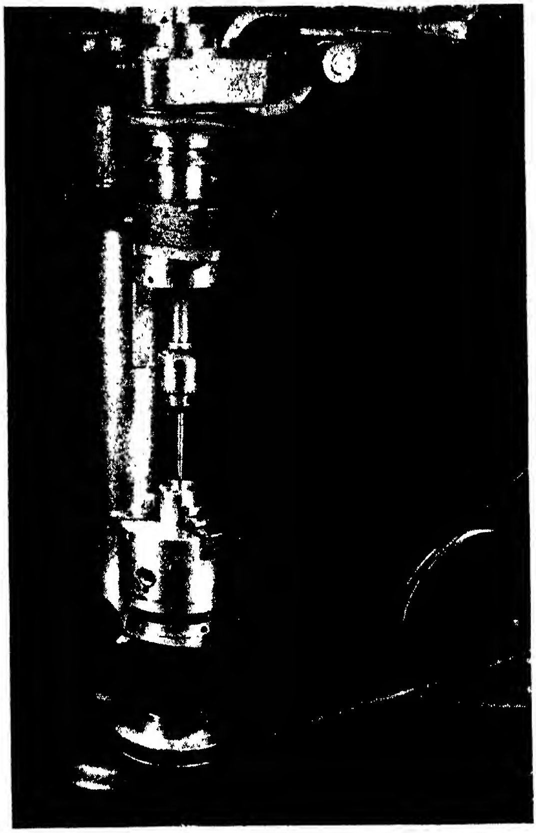


FIG. 2.—RIPPING OR REGRINDING A WIRE-DRAWING DIE
Bore size 0·040–0·100 in. (*Protolite, Ltd.*)

Die Polishing

Rough polishing paste is prepared with 1 carat of 200-mesh diamond powder to 8 c.c. of oil.* For most purposes, this is well mixed together and used whilst the powder is in suspension, but for very rough surfaces, small quantities of powder can be gathered from the bottom of the container (1 carat = 0·200 grm.).

Polishing paste is prepared with 1 carat of 400-mesh diamond powder to 10 c.c. of oil.

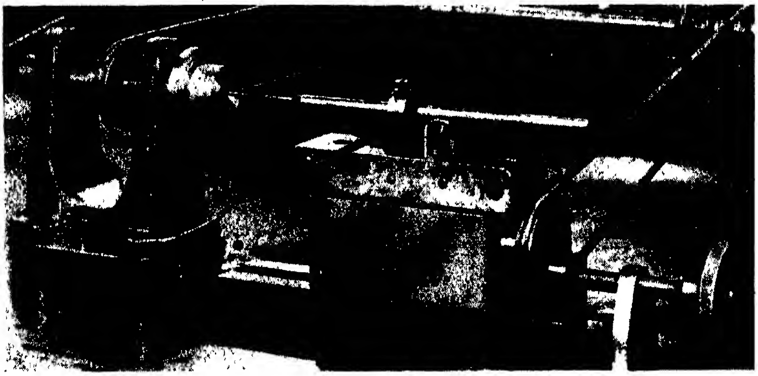


FIG. 3.—RIPPING OR REGRINDING A WIRE-DRAWING DIE
Bore sizes below 0·040 in. (*Protolite, Ltd.*)

Final polishing paste is prepared with 1 carat of 0–2-micron diamond powder to 15 c.c. of oil. When mixed, this can be used for several hours before further mixing is necessary.

(1 micron = $\frac{1}{1000}$ mm. = $\frac{1}{25000}$ in.).

FIG. 4.—"BLENDING THE RADII" OF A WIRE-DRAWING DIE
(*Protolite, Ltd.*)

Grinding

Die bores can be cleaned easily and quickly with rolled tissue paper.

Pick-up adhering to the die surface may be removed with a round, smooth file.

Checking Die Profiles

A die profile can readily be checked by plugging one end and pouring in an alloy consisting of 50 per cent. bismuth, 25 per cent. lead, and 25 per cent. tin. This alloy melts at

a temperature of 86° C. Additional useful information can be obtained by employing a tensile-testing machine to check die pull.

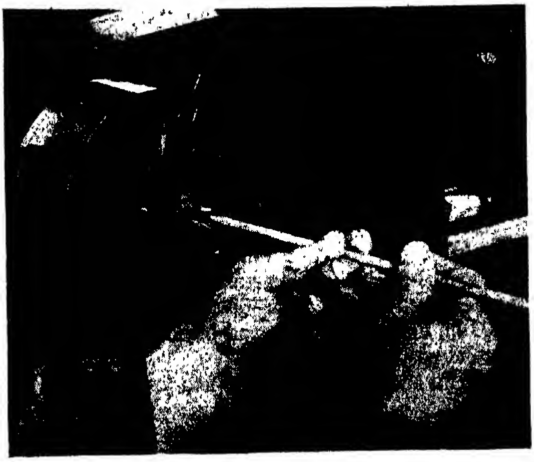


FIG. 5.—POLISHING A WIRE-DRAWING DIE
(*Protolite, Ltd.*)

WIRE-DRAWING DIES

If these dies require reshaping to rectify the drawing angles and the exit angles, the instructions given below should be carefully followed. As the methods vary somewhat according to the bore size, this preliminary operation will be dealt with under three separate headings:

(*a*) BORE SIZES 0·100–0·500 IN.—Fix die in cup or holder of ripping machine, insert needle which has been turned or ground to desired angle, and apply a paraffin or water mixture of silicon carbide, or boron carbide. Use 200-mesh powder in first instance, and finish with 400-mesh powder. Reverse die to regrind exit angle (see Fig. 1).

Needles must be replaced as wear occurs.

Note.—Boron carbide is the more rapid-cutting abrasive of the two mentioned.

(*b*) BORE SIZES 0·040–0·100 IN.—Dies between 0·040 in. diameter and 0·100 in. diameter are reshaped on vertical machines, using an oil mixture of 200- and 400-mesh diamond paste (see Fig. 2).

(*c*) BORE SIZES BELOW 0·040 IN.—Dies below 0·040 in. diameter are reshaped on very light horizontal machines, using an oil mixture of 200- and 400-mesh diamond paste.

Beeswax is used for centring and fixing the dies to the faceplates (see Fig. 3).

Blending Radii

After reboring, it will be necessary to make a smooth junction between the conical portion of the die and the curved entrance leading into it. This operation is called "blending the radii." The process is illustrated in Fig. 4. The die is fixed in a polishing head and the sharp corners in the entrance bell, and the run-out of the exit angle are blended into smooth curves by means of a diamond chip held in pliers.

Rough Polishing

Rough polish entrance bell, drawing angle, exit angle, and run-out, with 200-mesh diamond paste applied with a pointed hardwood stick until all rings and boring marks have been removed.

Initial Sizing and Polishing

Turn down dowel stick so that it fits tightly at meeting-point of the drawing and exit angles.

Reverse die, apply 200-mesh diamond paste, and work stick back and forth, keeping it in line with the axis of the die (see Fig. 5).

Use 200-mesh diamond paste until die is approximately 0·002–0·003 in. under finished size, then use 400-mesh diamond paste until die is approximately 0·0003 in. undersize. Polish and blend all corners throughout, using 400-mesh diamond paste.

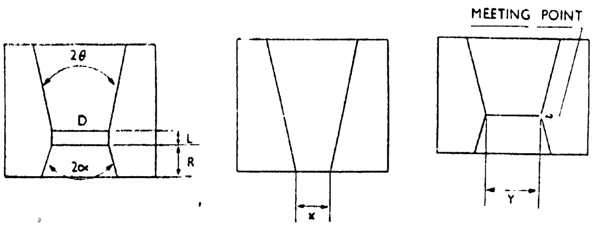
Several sticks are usually necessary to bring the die to size, as a tight fit is essential.

The following formulæ will be found of assistance for obtaining the desired length of bearing for the parallel portion of the die.

(*a*) The essential elements to be considered are:

1. Drawing angle.
2. Bearing or parallel.
3. Exit angle.

The desired drawing angle 2θ, length of bearing L, depth of exit angle and run-out radius R, value of exit angle 2α, and diameter D are all known.



The final profile is developed by means of three main operations, viz.:

Ripping or boring from the entrance.

Ripping or boring from the exit.

Lapping or cutting the bearing or parallel.

(*b*) The die is first ripped or bored right through with a needle ground to the correct value of the desired entrance angle. The operation is continued until the diameter of the bore at the exit X is such that the subsequent boring from the exit and the lapping or cutting of the bearing will give the correct value for the constants under A, above.

X is calculated from the constants by the following formula:

$$X = D - 2(L + R) \tan \theta.$$

FIG. 6.—SHAPING A BAR-DRAWING DIE BY DIAMOND-TOOL TURNING
(*Protolite, Ltd.*)

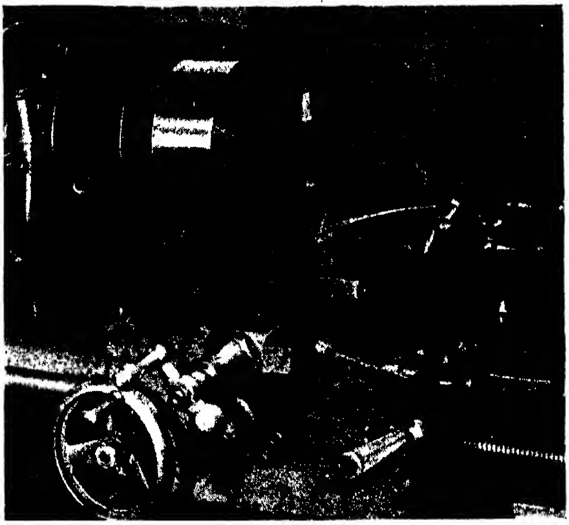


FIG. 7.—SHAPING A BAR-DRAWING DIE BY GRINDING
(*Protolite, Ltd.*)

(*c*) Then the die is bored from the exit, using a needle ground to the correct value of the exit angle, until the bore is opened out to a value Y.

The value Y can be determined from the formula—

$$Y = D - \frac{2L}{K}$$

where
$$K = \frac{\tan\theta + \tan\alpha}{\tan\theta \times \tan\alpha}.$$

It will be seen that K is constant as long as the same drawing and exit angles are used, and therefore tables can be compiled for the particular bore sizes in use.

(*d*) When the die is lapped or cut to the final size D, the bearing will be correct for length and position.

BAR- AND TUBE-DRAWING DIES

If bar- and tube-drawing dies should require reshaping, this can be done either by diamond-tool turning or by grinding.

Shaping by Diamond-tool Turning

This process is illustrated in Fig. 6. The die should be fixed in the lathe and the speed set so that the inside surface of the hole being bored revolves at approximately 100 ft. per minute. The diamond boring tool is placed in the toolholder, and the desired angles, bearing, and radii of the die turned. The depth of the cut should not exceed 0·001–0·002 in. A diamond tool of the type shown can be made by brazing or otherwise setting a diamond into a steel rod.

Shaping by Grinding

Internal grinding with metal-bonded or bakelite-bonded diamond impregnated wheels gives a surface which is superior to that obtained by diamond turning. For large-bore dies over 2½ in. diameter, grinding is recommended.

The following grades are recommended:

Rough grinding . .	50–70
Medium grinding . .	120–160
Fine grinding . . .	200–300
Fine grinding . . .	320–400
Very fine grinding . .	500–600

Wheel-speed range 4,500–5,500 surface feet per minute.

An adequate flow of coolant or lubricant is advisable, and kerosene, water, or any grinding solution, provided that it is not too strongly alkaline, is satisfactory. The machine must be rigid, and the largest possible quills employed (Fig. 7).

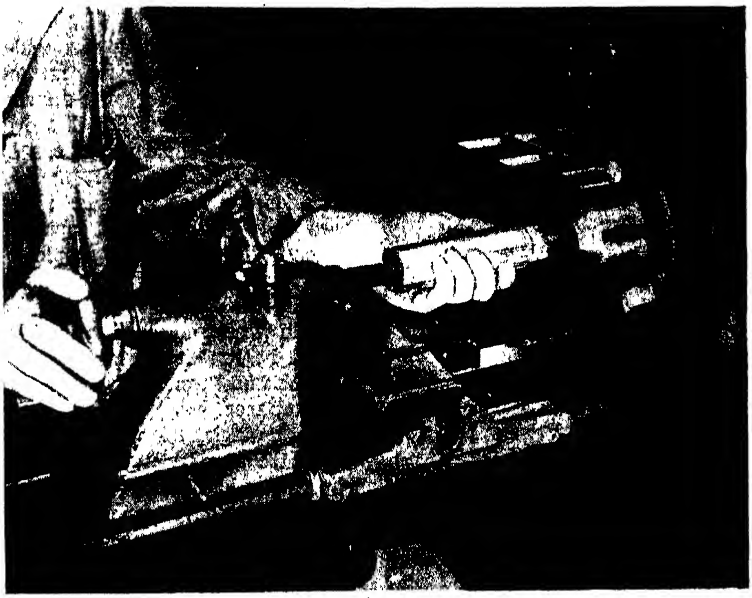


FIG. 8.—FINAL POLISHING OF A BAR-DRAWING DIE BEING CARRIED OUT ON A LATHE
(*Protolite, Ltd.*)

FIG. 9.—ROUGH POLISHING A BAR-DRAWING DIE
(*Protolite, Ltd.*)

FIG. 10.—RIPPING OR REGRINDING A SOLID-SHAPED DIE

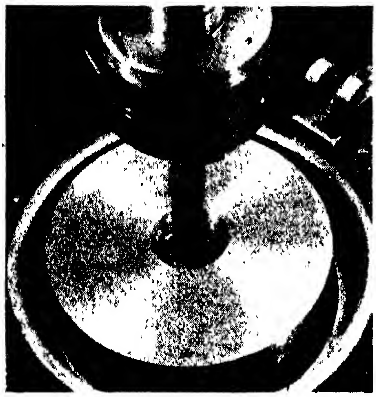


FIG. 11.—SIZING SOLID-SHAPED DIES (*Protolite, Ltd.*)

Polishing

For rough polishing dies under 2½-in. diameter bore, the method already described for wire-drawing dies is recommended. For dies over this size, more rapid results can be obtained by using a rotary flexible-shaft lapping machine (Fig. 9). A hard felt buffing wheel, approximately 1½ in. diameter, should be fixed to a standard type of machine, and 200-mesh diamond paste applied to both wheel and die. The machine should be run at maximum speed, and the wheel worked by hand over the entrance bell, drawing angle, and exit angle, taking care not to touch the bearing. Rough polishing should not be necessary in the case of dies which have been ground with the fine wheels recommended.

Initial Sizing and Polishing

For dies under 2½-in. diameter bore, the method already described for wire-drawing dies should be used. The sizing operation is carried out on a lathe, and the tailstock is used to keep the lap in line with the axis of the die.

It is recommended that dies over 2½-in. diameter bore are sized by grinding to within 0·0003 in. of finished diameter, and then polished with felt wheels fitted to a rotary lapping machine, using 400-mesh diamond paste, and blending the edges at each end of the bearing.

Final Sizing and Polishing

For dies up to 2½-in. diameter bore, the method already described for wire-drawing dies should be used. Fig. 8 shows the final polishing operation being carried out on a lathe, and it can be seen that the tailstock is used for applying pressure.

The final polishing of dies over 2½-in. diameter bore should again be carried

out on a rotary lapping machine, using a medium or soft felt wheel (Fig. 9). Two-micron diamond paste should be applied to the wheel and die and the wheel worked by hand over the entire profile. The operation should be continued until a high polish is obtained.

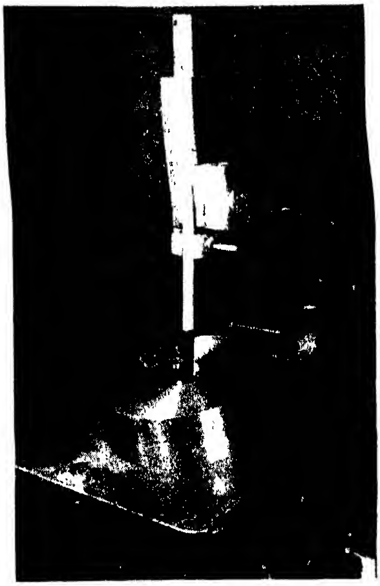


FIG. 12.—FINAL POLISHING OF A SOLID-SHAPED DIE (*Protolite, Ltd.*)

SOLID-SHAPED DIES

The following operations are employed for servicing, enlarging, and finishing solid-shaped dies. Ripping or regrinding, sizing, and grinding entrance and exit radii need be performed only on dies which have become severely scored or have to be appreciably enlarged, but the subsequent polishing operations should be performed as a matter of routine whenever signs of wear become evident.

FIG. 13.—POLISHING A HEADING DIE (*Protolite, Ltd.*)

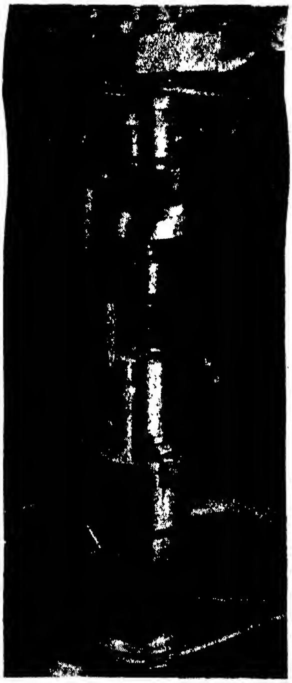


FIG. 14 (*above*).—COUNTERSINK FORMING OF A HEADING DIE
(*Protolite, Ltd.*)

The laps, which are used on lapping machines or hand-lapping devices, can be machined on standard machine tools equipped with the necessary indexing fixtures, if they are of regular section such as hexagon or square. Irregular or complicated laps usually have to be made up by skilled machinists. Mild-steel or hard-brass laps are recommended.

Ripping or Regrinding

The type of machine used for this work reciprocates the lap 600 times per minute, and also applies side pressure in such a way that each successive surface is lapped individually during the downward and upward stroke (Fig. 10). Careful control of this side pressure is necessary in the case of dies of irregular shape, where one surface tends to lap more readily than another.

The die is fixed in the holder, and the lap, which has been machined to the desired

FIG. 15 (*right*).—SURFACE GRINDING A HEADING DIE
(*Protolite, Ltd.*)

angle, inserted. A water or paraffin mixture of boron carbide should be applied. Two-hundred-mesh powder should be used in the first instance, and the die finished with 400-mesh powder. The die must be reversed to regrind the exit angle.

Sizing

Commencing laps should be tapered approximately 0·010 in. from end to end, the amount of taper being reduced as the die becomes near the finished size. The final laps must be machined dead parallel, and the surfaces made smooth.

Two-hundred-mesh boron-carbide paste should be used until the die is 0·004–0·005 in. under finished size, and then 400-mesh paste until the die is 0·0003 in. under finished size.

The die should then be cleaned thoroughly, and brought to size with a very accurate lap coated with 2-micron diamond paste.

Grinding Entrance and Exit Radii

Sharp edges which form at the top of the drawing angle and at the run-out of the exit angle during ripping operations can be removed by a rotary hand grinder employing silicon-carbide wheels, grit 100, grade 1.

Polishing

A device which reciprocates a lap at high speed is recommended for rough polishing. A hardwood or mild-steel lap is fixed in the machine and coated with 200-mesh diamond paste. The surfaces of the entrance angle, exit angle, entrance radius, and exit radius should be worked over, care being taken not to enter the bearing. The operation should be continued until a uniformly smooth finish is obtained.

For polishing and "blending the radii," the hand-lapping device should still be used, but medium or hardwood laps employed, coated with 400-mesh diamond paste. The entire profile should be worked over, and the edges at each end of the bearing blended.

Final Polishing

Two methods may be employed for the final polishing. The entire surface of the die profile can be worked over with the hand-lapping device, using soft or medium wood laps covered with 2-micron diamond paste, until a high polish is obtained. Alternatively, the final polishing can be carried out on a filing machine fitted with a wooden lap.

HEADING DIES AND EXTRUSION DIES

The following methods are used for servicing hard-metal dies having parallel, tapered, or radiused bores, such as heading dies or extrusion dies.

Lapping and Polishing

The die is fixed in a polishing head, and a wooden stick turned or ground so that it fits tightly in the bore. Two-hundred-mesh diamond paste is applied, and the stick is worked back and forth, care being taken to keep it in line with the axis of the die. It is most essential that a tight fit be maintained throughout this operation, and therefore several sticks are necessary, the number depending on the amount of material to be removed. Two-hundred-mesh paste should be used until the die is approximately 0·002 in. under finished size, and then 400-mesh paste applied to bring it to within 0·0003 in. of finished size.

Final Sizing and Polishing

The same method as described above should be used, but the laps should be coated with 2-micron diamond paste. In order to prevent bores from becoming bell-mouthed, the finished laps should be undercut, thus making the working position relatively short. If there are any edges or radii which need to be formed or polished, the method described for wire-drawing dies, under the heading "Blending Radii," should be used.

Countersink Forming

To form a countersink for heading and extrusion dies, the die is fixed in a lathe and the speed set at approximately 500 revolutions per minute. A steel needle is turned or ground to the value of the countersink angle required, and placed in the drill chuck. It is coated with 400-mesh diamond paste, and worked slowly into the die, using a reciprocating motion.

Fig. 14 shows this operation being carried out on a vertical machine which rotates the die, and also rotates and reciprocates the needle.

After grinding to size, the final polish should be applied by replacing the steel needle with a hardwood stick coated with 2-micron diamond paste.

Difficulty is sometimes encountered in grinding a countersink to the exact depth required, but provided that the angle is correct, this error can be rectified quite easily by surface grinding as shown in Fig. 15. Silicon-carbide wheels, grit 100, grade 1, are recommended. A very light feed must be used, or it will be found that the insert is left proud of the casing.

The above article has been compiled from the *Die Maintenance Manual* by the kind permission of Protolite, Ltd.

SPECIAL STEELS

CARBON steels are capable of being hardened to very high values, and by adjustment of the carbon content and of the tempering temperature wide values in the strength of the plain carbon steels are possible. There is, however, a proviso in this statement, which limits considerably the use of plain carbon steels in engineering constructions and renders necessary the production of special steels by means of alloy additions. This proviso is due to the fact that on cooling from the austenitic range, carbon steels transform to pearlite so quickly that a very rapid quenching speed is necessary if full hardening is to be achieved. Carbon steels, therefore, can only be fully hardened in very small sections, and one of the chief purposes of alloy additions is to enable larger sections to be fully hardened, in other words, to improve the hardenability of the steel. It is, of course, true that for many purposes steels are not used in the fully hardened condition, but if it is desired that the steel shall have the greatest ductility and toughness in a given tensile condition, then this is achieved by first giving the steel a full hardening treatment and then tempering back to the strength desired. A steel which during quenching partially transforms to pearlite, and thereby is not fully hard, will, in general, have lower ductility and toughness than a steel which has first been fully hardened, although both steels have been tempered to give identical tensile strengths.

Alloy additions may confer other virtues to the steel; for example, improved wear resistance, improved resistance to scaling at elevated temperatures and to corrosion, superior mechanical properties at elevated temperatures, high magnetic permeability, high coercive force such as is required by permanent magnets, greater or lower coefficient of thermal expansion, etc. Before describing types of alloy steels, therefore, a brief statement regarding the effects on steel of the various alloying elements normally used may be of interest.

Influence of Alloying Elements in Steels

ALUMINIUM is added to steel for various reasons, and the amount varies according to the rôle it has to play:

(*a*) As a deoxidiser it may be added in amounts up to 0·05 per cent.

(*b*) For the purpose of inducing fine-grain characteristics the aluminium addition varies from 0·04 to 0·10 per cent.

(*c*) Nitriding steels contain about 1·5 per cent. aluminium for the purpose of promoting the formation of an exceedingly hard surface layer when the steel is heated in ammonia gas at about 500° C.

(*d*) Heat-resisting steels may contain up to 15 per cent. aluminium; here it is added to promote scale resistance.

(*e*) For improved electrical resistance the aluminium content may be of the order of 5 per cent.

(*f*) Permanent magnets of the precipitation hardening type may contain, in addition to 24–30 per cent. nickel, from 9 to 13 per cent. aluminium.

CHROMIUM increases hardenability, and in association with carbon gives increased resistance to abrasion. It is unique in its effect of enhancing the resistance of steel to corrosion and scaling. In structural steels chromium is normally present in amounts up to about 3 per cent.

Simple chromium steels are used for ball bearings on account of their high hardness and wear resistance, but for most structural purposes chromium is used in conjunction with up to 4 per cent. nickel and/or small amounts of molybdenum or vanadium.

Chromium is an essential constituent of all stainless steels which contain, in the plain chromium type, 12–17 per cent. of this element. Austenitic stainless steels generally contain a minimum of 18 per cent. chromium with 8–12 per cent. nickel, and, for certain purposes, small amounts of other elements, such as molybdenum, titanium, or niobium (columbium), are added.

In heat-resisting steels chromium may be present up to 30 per cent. The high abrasion resistance resulting from the presence of chromium carbides renders steel with high chromium and high carbon (about 12 per cent. chromium and 1·0–2·5 per cent. carbon) suitable for die blocks, press plates, etc.

COBALT raises the tempering temperature of steel, and this is one of the reasons why it is added to the superior types of high-speed steel. It is also a valuable addition in creep-resisting steels.

Cobalt is used in proportions of up to 35 per cent. for magnet steels with high coercive force.

LEAD does not readily alloy with iron, but is added in amounts of the order of 0·25 per cent. to confer easy-machining characteristics. This element has less effect on the ductility and toughness of steels than other free machining additions, such as sulphur and selenium.

MANGANESE is used as a deoxidant in steel-making processes, and is therefore present in all steels; steels containing less than about 1·5 per cent. are not usually considered as alloy steels unless other alloy additions are present.

Small additions of manganese up to 1·5 per cent., with suitable adjustments of the carbon, improve the forging qualities.

Manganese has a powerful influence on hardenability, and as such is a useful alloying element.

Austenitic manganese steel contains 12–14 per cent. of manganese and about 1 per cent. of carbon. This steel has extremely high resistance to abrasion due to its great work-hardening capacity, especially when it is subjected during use to blows or severe surface distortion, as in stone-breaking machinery or in steel rails, particularly points and crossings.

MOLYBDENUM in its action is somewhat similar to chromium. It greatly increases hardenability and is used for this purpose in proportions up to 1 per cent. When added to low-alloy steels, it has a marked effect in reducing temper

brittleness (brittleness induced by slow cooling through the range 600°–400° C.)

In solid solution in steel molybdenum increases the strength and toughness of ferrite and improves resistance to creep at elevated temperatures. It retards grain growth and diminishes the softening which takes place on tempering. Added to stainless steels, molybdenum enhances the resistance to corrosion.

NICKEL, in amounts up to about 10 per cent., increases the tensile strength of low-carbon steels and also increases the toughness, although it has little effect on the ductility. In structural steels, nickel may be added in amounts up to 5 per cent. High-nickel content increases resistance to corrosion, and in combination with chromium, it is used in the austenitic rust- and heat-resisting steels.

Certain binary alloys have unique properties. Thus an alloy of iron containing 36 per cent. nickel has a very low coefficient of thermal expansion, whilst one with 78·5 per cent. nickel has a very high magnetic permeability in low magnetising fields. A steel containing about 12 per cent. nickel, 5 per cent. manganese, and 4 per cent. chromium has a high coefficient of expansion approaching that of certain aluminium alloys, and one containing 27–30 per cent. nickel and 17–20 per cent. cobalt has about the same expansion as a certain type of boro-silicate glass with which it can be made into a satisfactory glass to metal seal.

SILICON is a powerful deoxidiser and is present in small amounts in all steels. It raises the elastic limit, and is therefore added to silico-manganese spring steel to the extent of 1·5–2 per cent. Heat-resistant steels may contain about 4 per cent. of this element, as its ready oxidation assists in the formation of a coating of scale which is highly resistant to further oxidation.

Carbon-free alloys containing up to 4 per cent. silicon have high electrical resistance and low hysteresis loss, and are used as transformer steels. Alloys of iron and about 15 per cent. of silicon have good acid-resisting properties, but they are brittle, cannot be forged, and can only be fabricated as castings.

TITANIUM has powerful deoxidation properties, but its use as an alloy addition depends on its property of uniting with carbon to form an exceedingly stable carbide. Thus it may be added to mild steel as a means of preventing the formation of a martensitic zone during welding, or to the austenitic stainless steels to convert the carbon into a harmless form and so prevent intercrystalline corrosion attack. Niobium (columbium) is also used for these purposes.

TUNGSTEN in solution strengthens steel at normal and elevated temperatures. On account of the hardness of tungsten carbide and of its influence on secondary hardening, tungsten is almost indispensable in high-speed tool steels, molybdenum being its only substitute. A very high temperature, approaching the melting-point, is necessary to bring the carbide into solution for hardening.

VANADIUM is a carbide-forming element, and even in small amounts markedly increases hardenability and raises the temperature at which grain coarsening sets in. Vanadium also lessens the softening on tempering, and assists in inducing the secondary hardness in high-speed steels. It is an active grain refiner and a strong deoxidant.

Special Steels and their Uses

There is a wide variety of special steels, and the choice of the most suitable for any particular purpose is governed by many factors. Among these may be cited: size of component, strength, wear resistance, fatigue resistance, including the effect of notches, changes of section, corrosion or heat resistance, and other special physical requirements. Hot- and cold-working properties and

TABLE I.—COMPOSITION AND MAXIMUM RULING SECTIONS FOR VARIOUS ALLOY STEELS

B.S. No.	*Composition per cent.*						*Largest Diameter for the Tensile Strength Listed Below* *Tons per square inch*								
	C	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	40–50 *In.*	45–55 *In.*	50 60 *In.*	55–65 *In.*	60–70 *In.*	65–75 *In.*	70–80 *In.*	75–85 *In.*	100 *In.*
En 14B	0·2– 0·3	0·1– 0·35	1·3– 1·7	0·4– max.	—	—	4	2½	—	—	—	—	—	—	—
En 15	0·3– 0·4	0·1– 0·35	1·3– 1·7	—	—	—	all sizes	2½	⅞	—	—	—	—	—	—
En 16	0·25– 0·4	0·1– 0·35	1·3– 1·8		—	0·2– 0·35	—	all sizes	4	2½	1⅛	⅞	—		—
En 17	0·3– 0·4	0·1– 0·35	1·3– 1·8	—	—	0·35– 0·55	—	all sizes	all sizes	4	2½	1⅛		—	—
En 18	0·35– 0·45	0·1– 0·35	0·6– 0·95	—	0·8– 1·1	—	—	4	2½	1⅛	—			—	—
En 19	0·35– 0·40	0·1– 0·35	0·5– 0·8	—	0·9– 1·5	0·2– 0·4	—	all izes	4	2½	2½	1⅛	1⅛	—	—
En 21	0·25– 0·35	0·1– 0·35	0·35– 0·75	2·5– 3·5	0·3– max.	—	—	4	2½	—	—	—	—	—	—
En 22	0·35– 0·45	0·1– 0·35	0·5– 0·8	3·25– 3·75	0·3– max.	—	—	—	4	2½	—	—	—	—	—
En 23	0·25– 0·35	0·1– 0·35	0·45 0·7	2·75– 3·50	0·5– 1·0	opt. 0·65 max.		—	all sizes	all sizes	all sizes	2½	—	—	—
En 24	0·35– 0·45	0·1– 0·35	0·45– 0·7	1·3– 1·8	0·9– 1·4	0·2– 0·35		—	all sizes	all sizes	4	2½	1⅛	1⅛	1⅛ if O.H.
En 25	0·27– 0·35	0·1– 0·35	0·5– 0·7	2·3– 2·8	0·5– 0·8	0·4– 0·7	—	—	—	all sizes	all sizes	all sizes	4	2½	2½ if O.H.
En 26	0·36– 0·44	0·1– 0·35	0·5– 0·7	2·3– 2·8	0·5– 0·8	0·4– 0·7	—	—	—	—	all sizes	all sizes	all sizes	all sizes	4 if O.H.
En 27	0·25– 0·35	0·1 0·35	0·7– max.	3·0– 3·75	0·5– 1·3	0·2– 0·65	—	—	—	all sizes	all sizes	all sizes	4	—	—
En 28	0·25– 0·40	0·1– 0·35	0·7– max.	3·0– 4·5	0·75– 1·5	0·2– 0·65	—	—	—	—	all sizes	all sizes	4	2½	—
En 29	0·15– 0·35	0·1– 0·35	0·65– max.	0·4– max.	2·5– 3·5	0·3– 0·7	—	all sizes	all sizes	all sizes	all sizes	4	4	—	2½ if O.H.
En 30A	0·26– 0·34	0·1– 0·35	0·4– 0·6	3·9– 4·3	1·1– 1·4	—	—	—	—	—	—	—	—	—	2½ if A.H.
En 30B	0·26– 0·34	0·1– 0·35	0·4– 0·6	3·9– 4·3	1·1– 1·4	0·2– 0·4	—	—	—	—	—	—	—	—	6 if O.H.

O.H. = Oil Hardened. A.H. = Air hardened.

machinability may also have to be taken into account, and the final choice may also be governed by economical factors. The selection of the most suitable

TABLE II.—HEAT-TREATMENT AND USES OF VARIOUS ALLOY STEELS

B.S. No.	*Heat-treatment Temperature*			*Remarks*	*Typical Uses*
	Normalising	*Hardening*	*Tempering*		
	° C.	° C.	° C.		
En 14B	840–880	840–880 O.Q. or W.Q.	550–660	Normalise for 38–48 tons condition. Harden and temper for tougher tensiles.	Front and rear axles, bolts, crankshafts, and connecting rods for automobiles.
En 15	850	840–880 O.Q.	550–660	—	Axles, shafts, gas cylinders, connecting rods, studs and bolts, spindles.
En 16	—	830–860 O.Q.	550–660	Steels at the lower end of the composition range may be water hardened.	General engineering components.
En 17	—	830–860 O.Q.	550–660	Steels at the lower end of the composition range may be water hardened.	As En 16, but for larger sections.
En 18	—	850–870 O.Q.	550–700	Steels at the lower end of the composition range may be water hardened.	General engineering components, agricultural machinery, wear-resisting parts.
En 19	—	850–870 O.Q.	550–720	—	Superheater tubes, gun barrels, bolts.
En 21	—	830–850 O.Q. or W.Q.	550–650	—	High-tensile studs, bolts, and keys, connecting rods, valve rockers, propeller shafts, pinion shafts, automatic machine front and rear axle parts, steering levers.
En 22	—	840–860 O.Q.	550–650	—	Aero-engine auxiliary shafts, air-screw hub, connecting rods, bolts, pinion shafts, aero- and automobile-engine components.
En 23	—	820–850 O.Q.	550–660	After tempering O.Q. if molybdenum not present.	Connecting rods, bolts, aero-engine components, airscrew shafts, gearbox shafts.

TABLE II.—HEAT-TREATMENT AND USES OF VARIOUS ALLOY STEELS
(continued)

B.S No.	*Heat-treatment Temperature*			*Remarks*	*Typical Uses*
	Normalising	*Hardening*	*Tempering*		
	° C.	° C.	° C.		
En 24	—	820–850 O.Q.	660 max.	—	Axle tubes, high-duty connecting rods, and crankshafts, bolts, pinions, gears, tappets, magneto-drive shafts, gun barrels.
En 25	—	820–850 O.Q.	660 max.	—	Crankshafts, connecting rods, gears, axles, spindles, gun barrels, high-tensile aero-engine components, turbine shafts.
En 26	—	820–850 O.Q.	660 max.	—	As for En 25, but larger sections.
En 27 and En 28	—	820–850 O.Q.	500–660	—	Ordnance parts, gear and turbine parts, crankshafts, air-screw shafts, high-tensile bolts, shafts, and spindles.
En 29	—	890–910 O.Q. or A.C.	750 max.	Suitable for nitriding.	Superheater parts, aero-engine crankshafts, turbine shafts.
En 30A and En 30B	—	810–830 O.Q. or A.C.	250 max.	Air harden in sizes up to 2½ in.	Heavy duty gears, extrusion mandrels, transmission components, automobile rear-axle shafts.

A.C. = Air cool. O.Q. = Oil quench. W.Q. = Water quench.

steel is therefore not an easy one, and is best left to the expert, but it is hoped that what follows will be a useful guide.

For constructional steels reference should be made to the list of standard wrought steels given in British Standard Specification No. 970 and the commentary on this specification, namely B.S. 971. These documents give the analyses and properties to be expected from some seventy different alloy steels. Some of these are for special requirements such as springs, valves for internal-combustion engines, and for corrosion and heat resistance.

It is not possible in this chapter to give details of all these steels, but a selection has been made in Tables I and II of the more important ones in order

TABLE III.—MECHANICAL PROPERTIES SPECIFIED FOR VARIOUS TENSILE RANGES

Designation	*Ultimate Tensile Strength* *Tons per sq. in.*	*Yield Point Minimum* *Tons per sq. in.*	*Elongation per cent. on* $l = 4\sqrt{A}$ (min.)	*Izod Impact* *Ft.-lb.* *(min.)*	*Brinell Hardness*
Q . .	40–50	26*a*	22*b*	35	179–229
R . .	45–55	37	22*b*	40	201–255
S . .	50–60	38	20	40	223–277
T . .	55–65	44	18	40	248–302
U . .	60–70	48	17	35	269–321
V . .	65–75	52	16*c*	35	293–341
W . .	70–80	58	15*c*	30	311–375
X . .	75–85	63	14*c*	25	341–388
Y . .	80–90	68	14*c*	25	363–415
Z . .	100–110	85	10*d*	10*d*	444 (min.)

(*a*) 28 tons per square inch for En 14B and En 15.
(*b*) 20 per cent. elongation for En 14B Q, En 14R, En 15R.
(*c*) In the case of En 25, En 26, En 27, En 28, and En 29, the elongation is reduced in these conditions by 2 for sections of 4 in. diameter and above.
(*d*) The elongation per cent. and Izod value of En 24 in the 100-ton condition are 8 minimum.

TABLE IV.—COMPOSITION AND CORE PROPERTIES OF ALLOY CASE-HARDENING STEELS

B.S. No. and Type	*Composition per cent.*						*Specified Core Properties*	
	C	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*Ultimate Tensile Stress Tons per sq. in.*	*Izod Impact Ft.-lb.*
En 33 3 per cent. Nickel	0·1–0·15	0·1–0·35	0·3–0·6	2·75–0·35	0·3– max.	—	45	40
En 34 2 per cent. Nickel Molybdenum (lower carbon)	0·14–0·20	0·1–0·35	0·3–0·6–	1·5–2·0	—	0·2–0·3	45	40
En 35 2 per cent. Nickel Molybdenum (higher carbon)	0·2–0·28	0·1–0·35	0·3–0·6	1·5–2·0	—	0·2–0·3	55	25
En 36 3 per cent. Nickel Chromium	0·18– max.	0·1–0·35	0·3–0·6	3·0–3·75	0·6–1·0	—	55 60	35 30
En 37 5 per cent. Nickel	0·16– max.	0·1–0·35	0·45– max.	4·5–5·2	0·3– max.	—	40	50
En 38 5 per cent. Nickel	0·16– max.	0·1–0·35	0·60 max.	4·5–5·5	0·3– max.	0·15–0·30 (opt.)	65	30
En 39A 4·25 per cent. Nickel Chromium	0·12–0·18	0·1–0·35	0·5 max.	3·8–4·5	1·0–1·4	—	85	25
En 39B 4·25 per cent. Nickel Chromium Molybdenum	0·12–0·18	0·1–0·35	0·5 max.	3·8–4·5	1·0–1·4	0·15–0·35	85	25

to give some idea of the range of steels available, their heat-treatments, and the uses to which they are put.

Table II gives recommended forging, normalising, hardening, and tempering temperatures, and typical uses of the steels in Table I.

The mechanical properties specified for the various tensile ranges are given in Table III.

Alloy Case-hardening Steels

Where case-hardening steels are required with cores of higher tensile strength than is possible with plain carbon case-hardening steels, this is achieved by alloy additions, and in Tables IV and V are given the more important types specified in B.S. 970.

The heat-treatment of these steels and the properties to be expected from them in the form of 1⅛-in. diameter bars are:

TABLE V.—HEAT-TREATMENT AND PROPERTIES OF ALLOY CASE-HARDENING STEELS

B.S. No.	*Carburising*	*Refining*	*Hardening*	*Ultimate Tensile Stress Tons per sq. in.*	*Elongation per cent.*	*Izod Impact Ft.-lb.*
	° C.	° C.	° C.			
En 33	880–930	850–880 A.C., O.Q., or W.Q.	760–780 O.Q. or W.Q.	45 min.	18 min.	40 min.
En 34	880–930	850–880 A.C., O.Q., or W.Q.	760–780 O.Q.	45 min.	18 min.	40 min.
En 35	880–930	850–880 A.C., O.Q., or W.Q.	760–780 O.Q.	55 min.	15 min.	25 min.
En 36	880–930	850–880 A.C., O.Q., or W.Q.	760–780 O.Q.	T. 55–75 V. 65–80	15 min. 13 min.	35 min. 30 min.
En 37	880–930	850–880 A.C., O.Q., or W.Q.	750–780 O.Q.	40–60	20	50
En 38	880–930	850–880 A.C. or O.Q.	750–780 O.Q.	65	13	30
En 39A	880–930	850–880 A.C. or OQ.	760–780 O.Q. (temp. 200° C. max.)	85	12	25

A.C. = Air cool. O.Q. = Oil quench. W.Q. = Water quench.

The alloy case-hardening steels in general absorb carbon at a slightly lower rate than the unalloyed steels, and about 10 per cent. extra time should be allowed to produce the same case depth.

Case-hardened steels are used for those applications where a hard wear-resisting surface is required and where the core must be relatively soft and tough. The core must, however, have sufficient strength to support the hard case, and therefore the pressure imposed in service and the size of the component largely

determine the type of steel to be used. The 3 per cent. and 5 per cent. nickel case-hardening steels are used for gears, gudgeon pins, collets, certain rifle components, camshafts, clutch plates, magneto-drive wheels, and the like, whilst the 2 per cent. nickel-molybdenum and 5 per cent. nickel-molybdenum steel are favoured for rocker arms, shafts, pinions, bushes and gears, clutch plates and weights, levers, etc., requiring slightly harder cores. The 3 per cent. nickel-chromium case-hardening steels are used for gears, pinions, layshafts, cams, and camshafts, whilst the 4¼ per cent. nickel-chromium case-hardening steels are preferred for high-duty gears and pinions for aircraft engines, bearings for heavy rolls, gudgeon pins, camshafts, etc., requiring the highest core strength.

Nitriding Steels

Plain carbon steels, when exposed to ammonia at about 500° C. are not appreciably hardened, and although nitrogen is absorbed at the surface, the effect is mainly to embrittle the steel. There are certain special steels, however, which contain elements that readily form stable nitrides (such as aluminium, chromium, molybdenum, and vanadium), and these, after exposure to ammonia at about 500° C. for periods up to eighty hours or so, attain a very hard surface with a case depth after eighty hours of the order of 0·03 in. The most common nitriding steels are those of the LK type, containing essentially 1½ per cent. chromium and 1 per cent. aluminium, which produce after nitriding a surface hardness of 1,050–1,100 Diamond Hardness Number, and those containing about 3 per cent. chromium and 0·4–1·2 per cent. molybdenum, which after nitriding harden up to 800–950 Diamond Hardness Number. The latter type of steel has a tougher case than that of the chromium-aluminium type. Each type of steel is made with varying carbon contents according to the core strength desired, which can also be controlled by adjusting the tempering temperature.

Details of the nitriding steels specified in B.S. 970 are as follows:

TABLE VI.—COMPOSITION AND HEAT-TREATMENT OF NITRIDING STEELS

B.S. No.	*Composition per cent.*							*Heat-treatment before Nitriding*	
	C	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*V*	*Hardening*	*Tempering*
								° *C.*	° *C.*
En 40A	0·1–0·2	0·1–0·35	0·4–0·65	0·4 max.	2·9–3·5	0·4–0·7	—	890–910 O.Q.	550–750
En 40B	0·2–0·3	0·1–0·35	0·4–0·65	0·4 max.	2·9–3·5	0·4–0·7	—	890–910 O.Q.	550–750
En 40C	0·3–0·5	0·1–0·35	0·4–0·8	0·4 max.	2·5–3·5	0·7–1·2	0·1–0·3	900–940 O.Q.	550–650
							Al.		
En 41	0·18–0·45	0·1–0·45	0·65 max.	0·4 max.	1·4–1·8	0·1–0·25	0·9–1·3	890–910 O.Q.	550–720

Table VII gives typical mechanical properties obtainable in these steels in the form of 1⅛-in. bars.

TABLE VII.—TYPICAL MECHANICAL PROPERTIES OF NITRIDING STEELS

B.S. No.	*Type*	*Carbon Content per cent.*	*Oil Hardened*	*Tempered*	*Y.P.* *Tons per sq. in.*	*U.T.S.* *Tons per sq. in.*	*Elong. per cent.*	*Izo impact* *Ft.-lb.*	*Uses*
			C.	*C.*					
En 40A	HCM7	0·2	900	600 650 700	45·6 40·8 35·6	55 1 49·6 44·4	22·0 25·0 27·0	74 83 88	Aero - engine cylinders.
En 40B	HCM5	0·3	900	600 650 700	63·2 53·3 41·8	72 1 63·3 52 2	20·0 22·0 23·0	50 58 72	Crankshafts, air-screw shafts.
En 40C	HCM3	0·4	900	550 600 650	– – 59·0	105·0 84 2 66·4	11·0 17·0 20·0	30 52 75	Ball races, die blocks, moulds for plastics, pottery, etc.
En 41	LK7	0·2	900	600 650 700 750	31 5 30·1 28·6 26·2	42·5 37·1 28·6 26 2	28·0 29·5 30·0 35·0	65 70 78 95	Wear-resisting parts not requiring high core strength for textile plant, boot and shoe machinery, etc.
En 41	LK5	0·3	900	600 650 700	48·8 44·0 38·0	62·4 57·6 50·6	19·0 23·0 28·0	44 54 67	Parts requiring medium core strength, for pump rods, cylinder liners.
En 41	LK3	0·4	900	600 650 700	62·1 55·6 44·4	68·2 62·2 53·6	16·0 20·5 23·0	35 40 55	Rolls, die blocks, brick press plates, gudgeon pins, timing wheels.

Apart from the high surface hardness and abrasion resistance imparted to nitriding steels by the nitriding process, there are other advantages which must be noted by the engineer. Most important of these is the increase in fatigue resistance of the nitrided parts, due in part to the increased surface hardness, but mainly to the fact that the surface layers, after nitriding, are in a state of compressive stress. In particular, nitrided articles are much less notch sensitive

under fatigue conditions than unnitrided steels. Nitriding also improves the corrosion resistance of steels against the action of fresh water, sea water, steam, or moist atmosphere.

Spring Steels

Spring steels are essentially hard steels with high elastic limits. Cheap springs are made from carbon steel with 0·5–1·2 per cent. carbon, but more reliable properties are provided by silico-manganese and chromium-vanadium steels, the former being generally used for laminated springs and torsion bars for automobiles and the latter for coil springs for aero-engine valves. The most favoured types of these steels are:

TABLE VIII.—COMPOSITION AND HEAT-TREATMENT OF SPRING STEELS

B.S. No.	*Type*	*Typical Composition per cent.*					*Heat-treatment*		*Brinell Hardness*
		C	*Si*	*Mn*	*Cr*	*V*	*Harden-ing*	*Temper-ing*	
							° C.	° C.	
En 45	Silico-managanese	0·5–0·65	1·5–2·0	0·7–1·0	—	—	850–900	About 480	380–450
En 50	Chrome-vanadium	0·4–0·5–	0·1–0·35	0·5–0·7	1·0–1·5	0·15 min.	850–900 O.Q.	About 440	380–450

Ball-race Steel

Ball and roller bearings are almost invariably made from a steel containing 1 per cent. carbon and 1·5 per cent. chromium to En 31 specification containing the following percentage:

C	*Si*	*Mn*	*Cr*
0·9–1·2	0·1–0·35	0·3–0·75	1·0–1·6

Bars must first be annealed by soaking at 800–820° C., followed by slow cooling in order to obtain the carbides in the spheroidised condition and to soften the material for machining. Hardening consists of heating to 800–840° C. and quenching in oil or water; tempering is usually carried out at 130–180° C.

Alloy Tool Steels

(A) HIGH-SPEED STEELS

All high-speed steels contain tungsten (or molybdenum), the chief virtue of which is to raise the temperature at which softening of the steel occurs, so that the steel is not tempered at the temperatures the tools attain in service. Cobalt increases the temperature at which softening occurs, and therefore is added when higher speeds are used or hardened materials are being cut. The additions of cobalt, however, reduce the toughness of the steel, and therefore are not so

satisfactory for intermittent cuts or for break-through drills. Analyses, heat-treatment, and applications of the typical high-speed steels are given in the table below.

TABLE IX.—COMPOSITION, HEAT-TREATMENT, AND USES OF VARIOUS HIGH-SPEED TOOL STEELS

Type	*Composition per cent.*								*Heat-treatment*		*Applications*
	C	*Si*	*Mn*	*Cr*	*Mo*	*V*	*W*	*Co*	*Hardening*	*Tempering*	
									° C.	° C.	
14 per cent. W	0·60	0·15	0·20	3·50	—	0·65	14·0	—	1,280–1,300	560–580	Lathe, slotter, and planer tools, drills, and cutters for general shop use.
									1,280–1,300	600–610	For tools subject to shock, intermittent cutting or non-rigid working conditions, e.g. slitting saws, taps and reamers, chisels, punches, and pneumatic tools
18 per cent. W	0·75	0·15	0·20	4·25	—	1·10	18·0	—	1,300–1,320	560–580	General-purpose high-speed steel for lathe shaping and planing tools, drills, cutters, taps, thread chasers, broaches, reamers, etc.
22 per cent. W	0·73	0·15	0·20	4·80	—	1·40	22·0	—	1,300–1,320	560 580	For heavy-duty lathe-slotter and planer tools
18 per cent. W 5 per cent. Co	0·75	0·15	0·20	4·0	0·70	1 40	18·0	5·25	1,300–1,320	560–580	For cutting tools demanding greater red-hardness, especially under conditions of continuous cutting
18 per cent. W 10 per cent. Co	0·78	0·15	0·20	4·80	1·0	2·0	18·8	9·3	1,320–1,340	560–580	For tools demanding very high cutting efficiency and red-hardness, e.g. cutting of medium and high-tensile alloy steels at high rates of removal under continuous cutting conditions

High-speed steels are hardened from very high temperatures, and therefore care should be taken, by the use of controlled furnace atmospheres or special salt baths, to avoid decarburisation during the treatment. The tools are quenched either in oil or in an air blast in the case of small sections. It is advisable to transfer to the tempering furnace whilst the tools are still hand warm after

quenching, in order to reduce the tendency to cracking, especially in tools containing keyways or other acute changes of sections. Improved results are obtained if tools are tempered twice at the recommended temperature, in order more completely to transform any austenite retained after hardening.

(B) Alloy Tool and Die Steels

There is a wide variety of steels on the market to suit special requirements, and it will only be possible to give a selection of these. Table X has been chosen to cover the majority of requirements.

TABLE X.—COMPOSITION, HEAT-TREATMENT, AND USES OF VARIOUS ALLOY TOOL AND DIE STEELS

Type	*Typical Composition per cent.*								*Heat-treatment*		*Applications*
	C	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*V*	*W*	*Hardening*	*Tempering*	
									° *C.*	° *C.*	
C, Mn, non-shrinking	0·92	0·30	1·75	—	—	—	—	—	760–780 O.Q.	140-150	Gauges, dies, jigs, and similar tools required in the hardest condition.
									760–780 O.Q.	200–260	Taps, screwing dies, and broaches.
									760–780 O.Q.	250–260	Punches and heavier dies requiring a slightly toughened condition.
Cr, W, non-shrinking	0·95	0·25	0·95	—	0·80	—	—	1·0	790–810	As for carbon-manganese steel	For similar requirements to carbon manganese, but with increased wear resistance.
Silicon-nickel-chrome chisel steel	0·44	1·0	0·65	3·0	0·65	—	—	—	900–950 A.C. (or when required	200–220	For chisels, etc.
									850–800 O.Q.)	Tempering not necessary	Coal-cutter picks, shear blades.
1 per cent. W steel	1·2	0·25	0·25	—	—	—	—	1·25	780–800 W.Q.	200–250	Taps, screwing dies, drills, cutters, hacksaw blades.
4 per cent. W steel	1·35	0·15	0·35	—	—	—	—	4·0	800–820 W.Q.	150–200	Boring and rifling tools, finish turning tools for chilled iron and non-ferrous materials. Cold-drawing dies, engraving tools.

TABLE X.—COMPOSITION, HEAT-TREATMENT, AND USES OF VARIOUS ALLOY TOOL AND DIE STEELS (*continued*)

Type	*C*	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*V*	*W*	*Hardening*	*Tempering*	*Applications*
	Typical Composition per cent.								*Heat-treatment*		
									° C.	° C.	
12–13 per cent. Cr die steels	0·8–2·2	0·30	0·30	—	12·0 to 13·0	0·5–1·0	up to 1·0		980–1,020 A.C. or O.Q.	200–220 or 400–500	Blanking, forming, and trimming dies and punches, moulds for plastics, thread-rolling dies, and masters for cold-hobbing work. The carbon content and tempering treatment are adjusted according to whether maximum hardness or increased toughness is required.
Tung-sten-chrome	0·52	0·70	0·55	—	1·2	—	—	2·30	840–860 O.Q.	200–280	For heavy punches, press, and forming tools.
Tung-sten-chrome	0·35	0·50	0·25	—	1·0	—	—	1·8	810–820 W.Q.	180–250	Rivet snaps, punches, hand chisels, caulking tools, etc.
High-carbon tungsten	1·90	0·15	0·25	—	0·6	—	—	6·0	830–850 W.Q.	150–200	Cold-drawing dies, cartridge-case drawing dies.
10 per cent. hot W die steel	0·2–0·4	0·15	0·25	—	2·25	0·45	0·20	10·0	1,130–1,150 A.C. or O.Q.	580–690	Hot extrusion dies and mandrels. Cold rotary slitting cutters, hot and cold shear blades, hot working punches, dies, piercing tools, and die-casting moulds and cores.
543 Ni, Cr, Mo steel	0·09	0·60	0·60	4·80	3·90	3·0	—	—	900 O.Q.	400 for maximum hardness or 600–650° C. for lower hardness	Hot shear blades, piercing tools, and punches. Die-casting dies.

A.C. = Air cool. O.Q. = Oil quench. W.Q. = Water quench.

Stainless and Heat-resisting Steels

Stainless steels may be divided into three categories:

(1) Ferritic steels, containing low carbon and chromium from 12 to 30 per cent.

(2) Martensitic steels, containing medium carbon contents with chromium

TABLE XI.—COMPOSITION, HEAT-TREATMENT AND PROPERTIES OF STAINLESS STEEL

B.S. No.	*Composition per cent.* C	Si	Mn	Ni	Cr	Mo	Ti	Nb	*Heat-treatment* Hardening	Tempering	*Properties (minima)* U.T.S. Tons per sq. in.	Eln. (per cent)	Izod Ft. lb.
									° C.	° C.			
56A	0·12 max.	1 max.	1 max	1 max.	12–14	—			950–1,020 O.Q. or A.C.	600–750	35	25	45 if < 2 in. 25 if > 2 in.
56B	0·12–0·18	1 max.	1 max.	1 max	12–14	—	—		950–1,020 O.Q. or A.C.	600–750	45	20	25 if < 2 in. 20 if > 2 in.
56C	0·18–0·25	1 max.	1 max	1 max.	12–14	—		—	950–1,020 O.Q. or A.C.	600–750	45	20	25 if < 2 in. 20 if > 2 in.
56D	0·25–0·35	1 max.	1 max.	1 max.	12–14	—		—	950–1,020 O.Q. or A.C.	600–750	45	20	25 if < 2 in. 20 if > 2 in.
57	0·25 max.	0·1–1·0	1 max.	1·0–3·0	15·5–20 0	—		—	950–1,020 O.Q. or A.C.	550–650	55	15	25 if < 2 in. 15 if > 2 in.
									Softening				
58A	0·16 max	0·2 min.	2 max.	7–10	17–20		—	—	950–1,150 A.C. or W.Q.		35	30	50 if < 2·5 in.
											30	30	50 if > 2·5 in.
58B	0·15 max.	0·2 min.	2 max.	7·10	17–20	—	4 C min.	—	950–1,150 A.C. or W.Q.		35	30	50 if < 2·5 in.
											30	30	50 if > 2·5 in.
58F	0·15 max.	0·2 min.	2 max.	7–10	17–20	—	—	8 C	950–1,150 A.C. or W.Q.		35	30	50 if < 2·5 in.
											30	30	50 if > 2·5 in.
58J	0·12 max.	0·2 min.	2 max.	8–12	17–20	2·5–3·5	—	—	950–1,150 A.C. or W.Q.		35	30	50 if < 2·5 in.
											30	30	50 if > 2·5 in.

A.C. = Air cool. O.Q. = Oil quench. W.Q. = Water quench.

contents of 11–20 per cent. Small amounts of nickel up to 3 per cent. may also be present.

(3) Austenitic steels, usually containing a minimum of 12 per cent. chromium; with high proportions of nickel, generally exceeding 8 per cent., and it is preferable that the sum of the chromium and nickel contents exceeds about 25 per cent. The austenitic stainless steels, unless the carbon content is very low (below 0·03 per cent.), may be susceptible to intercrystalline corrosion attack if, as a result of welding or hot working, they are heated within or allowed to cool slowly through the range of temperatures between 400° C. and 900° C. This is responsible for the so-called weld decay in welded structures. This feature may be obviated by additions to the steel of stabilising elements. The most important of these are titanium, which is added in amounts of at least four times the carbon content, and niobium (columbium), which is added in amounts of at least eight times the carbon content.

Molybdenum may be added to the austenitic stainless steels if increased corrosion resistance is required in certain reagents, such as sulphuric, acetic, and phosphoric acids.

The range of stainless steels available at the present time is very wide, and

TABLE XII.—COMPOSITION, HEAT-TREATMENT, AND PROPERTIES OF HEAT-RESISTING STEELS

En No.	Type	*Composition per cent.* C	Si	Mn	Ni	Cr	W	*Heat-treatment* *Hardening*	*Tempering*	*Properties* *U.T.S. Tons per sq. in.*	*Eln. per cent.*	*Izod. Ft.-lb.*	*Brinell Hardness*
								° C.	° C.				
52	Silicon-chrome valve steel	0·4–0·5	3·0–3·75	0·3–0·6	0·5 max.	7·5–9·5	—	1,000–1,050 O.Q. or A.C.	650–850	*61	25·0	—	255–293
54	NiCrW-valve steel	0·35–0·5	1·0–2·5	1·5 max.	10·0 min.	12·0–16·0	2–4	*Softening* 950–1,020 A.C. or W.Q.		*63	23·5	15 min.	302 max.
59	CrNiSi-valve steel	0·74–0·84	1·75–2·25	0·2–0·6	1·15–1·65	19·0–20·5	—	1,050–1,080	700–750	—	—	—	*Y*
55	CrNiW steel	0·18–0·45	1·0–2·5	1·0 max.	6·0–12·0	17·0 min.	2–4	*Softening* 950–1,020 A.C. or W.Q.		*46	32·0	20 min.	302 max.
*	CrNiNb steel	0·13	0·6	1·2	12·0	18·0	Nb 1·3	*Softening* 1,050 A.C. or W.Q.		*41	58·0	50	175
*	25–20 CrNi steel	0·14	1·4	0·8	21·5	24·5	—	*Softening* 1,050 A.C. or W.Q.		*49	68·0	—	200

* Typical values are quoted here.
Y must give a hardness in excess of Rockwell C47 (490 Diamond Hardness number) in the hardened condition.

since many have been introduced for special requirements, it is always advisable to seek the guidance of the steel supplier when choosing the appropriate steel for the application in mind. It is only possible, in this chapter, to mention the more important of the stainless steels quoted in B.S. 970. These are listed in Table XI.

Heat-resisting Steels

Plain carbon and low-alloy steels are not suitable for use at temperatures above about 550° C., where they are subject to relatively high stresses, or where scaling of the steel may rapidly initiate failure. Above about 350° C. these steels do not behave under stress as they do at normal temperatures, where, when a tensile load is applied below the breaking stress, the steel stretches up to a certain amount and then ceases to stretch further. At higher temperatures cessation of stretching never occurs, and even under the action of very low tensile stresses the steel will continue to stretch with time. This phenomena is known as "creep," and in the design of parts working at elevated temperatures, cognizance must be taken of the extent of the creep which takes place with time under various conditions of stress and temperature. It is also clear that the steel must not scale rapidly at the operating temperature. In low-alloy steels, molybdenum is a useful element to add to steel to reduce the creep rate, but for high temperatures other alloy additions in substantial amounts must be made. Figs. 1 and 2 show creep and rupture curves respectively for a number of steels, and indicate the advance made in recent years in the direction of improved high-creep-strength steels operating at high temperatures, especially those required for the jet engine and gas turbine. Particulars of such steels should be obtained from the steel suppliers, but Table XII gives a list of the more common heat-resisting steels (not necessarily designed for creep resistance) mentioned in B.S. 970.

It is not possible in this chapter to go into more detail on these steels and to give data regarding the mechanical and creep properties at elevated temperatures. For the special applications for which these steels are required, it is always advisable to seek the guidance of the steel suppliers, but some useful data regarding safe working stresses may be obtained from British Standards 1113 and 1500.

HINTS ON HEAT-TREATMENT OF THE SPECIAL STEELS

Whilst the steels with low carbon content may in general be put straight into a furnace held at the hardening temperature, it is always advisable, especially for the higher alloy steels, to preheat slowly to the hardening temperature, especially in the case of complex or irregular sections. Once the part has reached the hardening temperature, it should be held at that temperature for threequarters to one hour for every inch of diameter or equivalent ruling section. The part is then quenched in the appropriate manner as indicated in the tables. It is advisable to withdraw the part from the quenching bath before it has cooled down completely, that is, whilst it is still hand warm, and to

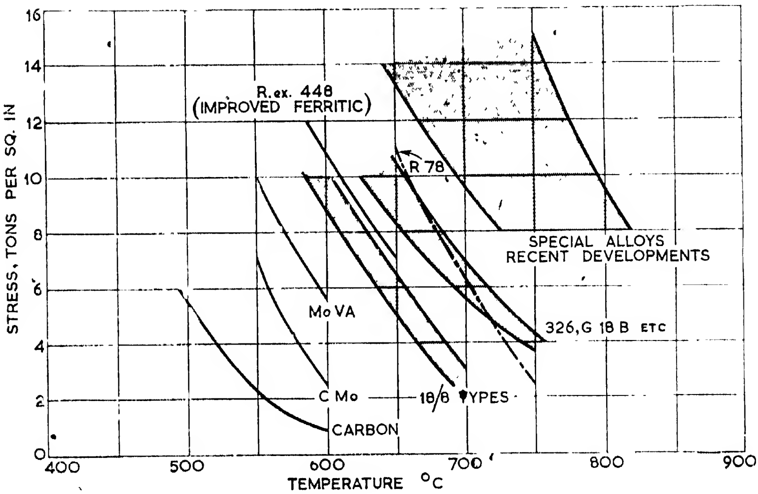


FIG. 1.—STRESS TEMPERATURE CURVES FOR 0·2 PER CENT. ELONGATION IN 1,000 HOURS

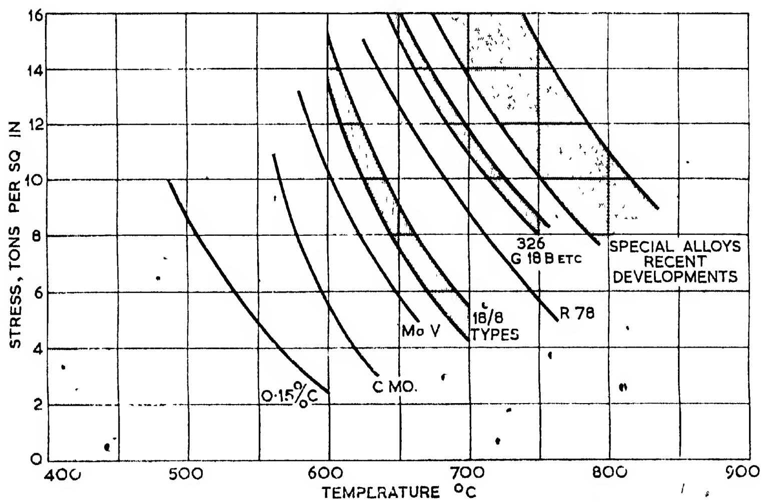


FIG. 2.—STRESS TEMPERATURE CURVES FOR FRACTURE IN 1,000 HOURS

transfer it immediately to the tempering furnace. One to one and a half hours per inch of diameter or ruling section is recommended as a suitable heating time at the selected temperature, and after tempering the part may be cooled in air except in the case of certain steels, such as the nickel-chromium steels without molybdenum, which may develop temper-brittleness if allowed to cool slowly through the range 600–400° C. In the latter cases cooling off in oil or water will improve the notch-impact value of the product when in small sections, but increases the internal stress in the steel, and this may give rise to distortion in machining.

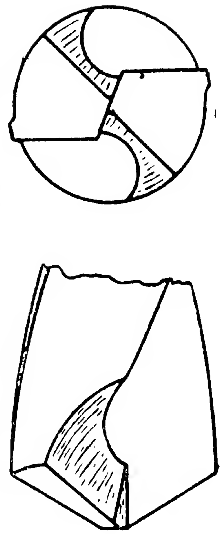


FIG. 3.—DRILL POINTS ARE GROUND TO PROVIDE CUTTING EDGES ON CHISEL POINT FOR REDUCED CUTTING PRESSURE

The austenitic corrosion and heat-resisting steels are not capable of being hardened by heat-treatment. They can only be hardened by cold-working operations in the form of sheet, strip, small section bars and wires, or to a limited extent in certain cases of larger bars and forgings by finishing the forging or rolling operations when the steel is at a dull red or black heat. The austenitic steels are usually heat-treated to obtain the fully softened condition. For this purpose they are heated to the appropriate temperature quoted in the tables and then cooled as rapidly as possible. The recommended temperatures should not be exceeded, otherwise grain growth may be excessive, and in the case of the corrosion-resisting austenitic steels they are more liable to be susceptible to intercrystalline corrosion on reheating in the critical range 400–900° C. The stabilised corrosion-resisting steels may be air cooled after heating for softening, but the non-stabilised steels may only be air cooled in the form of sheet, strip or wire if they are less than about 20 gauge thick.

MACHINING OF THE SPECIAL STEELS

Difficulties when machining high-tensile steels are not only related to the increased abrasive factor of the harder material, but also to the strength of the chip or swarf produced. The combination of high tensile strength with a good measure of ductility gives a continuous type of swarf which, in the case of turning operations, leads to heavy chip pressure, and when drilling or tapping, a tenacious strong chip which does not break readily to clear the flutes. Of further significance is the relative freedom from non-metallic inclusions of high-tensile steels when produced from the electric arc furnace. This adds to the chip strength in contrast to the chips produced from free-cutting steels which have the addition of lead, etc., the object of which is to reduce the ductility of the swarf.

TABLE XIII.—DRILL SPEEDS AND FEEDS

Diameter of Drill in.	*Speed r.p.m.*	*Feed per revolution in.*	*Diameter of Drill in.*	*Speed r.p.m.*	*Feed per revolution in.*
$\frac{1}{16}$	1,200	Hand feed	$\frac{9}{16}$	245	0·0075
$\frac{1}{8}$	850	Hand feed	$\frac{5}{8}$	230	0·0080
$\frac{3}{16}$	610	0·0040	$\frac{11}{16}$	220	0·0085
$\frac{1}{4}$	460	0·0045	$\frac{3}{4}$	210	0·0090
$\frac{5}{16}$	370	0·0055	$\frac{13}{16}$	200	0·0095
$\frac{3}{8}$	315	0·0055	$\frac{7}{8}$	190	0·0100
$\frac{7}{16}$	280	0·0060	$\frac{15}{16}$	180	0·0105
$\frac{1}{2}$	260	0·0070	1	170	0·0110

The application of tungsten-carbide tools has overcome machining troubles due to the abrasive factor of high-tensile steels on most semi-roughing and finish-turning operations, steels of 100 tons per square inch tensile strength being commercially machined with carbide lathe tools and face milling cutters. For the operations of sawing, drilling, and tapping, and extremely heavy duty turning operations on large forgings, tungsten-carbide tools have not been successfully applied, and comments regarding these operations, which present difficulties when using high-speed steel tools, may be of interest.

It should be clearly appreciated that high-speed steel tools show to the best advantage when operating at relatively low speeds, maintaining medium to heavy feeds or tooth loading. Little success is possible when machining high-tensile steels at high peripheral speeds with light feeding. This gives premature failure due to abrasion and heat generation, with the further possibility of work hardening the more highly alloyed steels. It is good practice to maintain a constant feed per revolution or tooth loading irrespective of the tensile strength of the material, meeting the more abrasive high-tensile range by a marked reduction in peripheral speed. Given the correct peripheral speed, it is often seen that a steel of tensile strength of say 80–85 tons will prove less difficult to drill or tap than the same analysis reduced in strength to 65 tons tensile. This is entirely due to the characteristics of the chip produced, the harder material, being less ductile, thus breaking more readily and clearing the flutes of the tool.

For the machining of alloy steels of high tensile strength, tools of the tungsten-cobalt type show to advantage on turning and milling operations. Progressive cobalt additions improve the red-hardness or resistance to softening of the high-speed steel, but only with increased brittleness. The tool designer accommodates these increased brittleness factors by modification to helix angle (for drills), reduced clearance and rake angles, etc. (for lathe tools, etc.), thus ensuring maximum support to the cutting edges of the tool. The tool user should ensure maximum rigidity of set-up with correct maintenance of these cutting angles during resharpening. Steels to a maximum tensile strength of 85 tons can be machined with high-speed tools, but beyond this range of tensile strength,

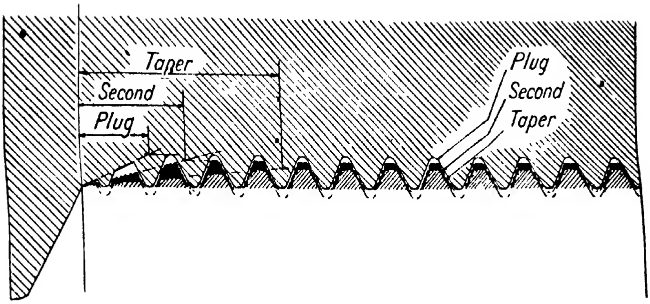


FIG. 4.—SERIAL TAPS WITH THE TAPER AND SECOND TAPS UNDER SIZE ARE RECOMMENDED FOR USE ON HIGH-TENSILE AND AUSTENITIC WORK-HARDENING STEELS

machining operations cannot be considered commercial unless carbide tools are employed or repeated regrinding of high-speed steel tools working at very low speeds is accepted.

Turning

For heavy-duty machining, tools with a straight cutting edge and a plan approach angle of 30–45° ensures that the heavy chip load is well distributed along the cutting edge, giving a chip of uniform thickness, with the flow of chip normal to the cutting edge. The use of round-nosed lathe tools gives crowding of the chip, which leads to local cratering and premature failure. The front to back top-rake and side-rake angles should be adjusted until the chip cavity worn on the top face of the tools forms sufficiently away from the cutting edge to give maximum tool life. If the tool fails by fusion of the cutting edge or extensive rubbing down of the front clearance angles, the peripheral speed employed is excessive. The tool running at optimum peripheral speed and correctly ground ultimately fails by the progressive development of the chip cavity worn on the top face towards the cutting edge, finally giving failure by the collapse of the weak edge produced.

Employing tungsten-cobalt high-speed steel tools, front top-rake angles of 5–8°, with a side top-rake angle of 10–15° facilitate the free sliding of the chip across the tool face, and with front and side clearance angles just sufficient to prevent the flank of the tool rubbing on the work, ensure maximum support to the cutting edges.

Drilling

For steels up to the general range of 65 tons tensile, the standard 18 per cent. tungsten high-speed drill is generally applied. Above this range of tensile, drills with the increased surface hardness given by nitriding show to marked advantage in life between grinds. For the extreme range of tensile strength, tungsten-

cobalt drills of strengthened design, given by shortened flutes, increased web thickness, and slower helix angle, are recommended. The following hints apply to high-tensile drilling, and also for the drilling of austenitic work-hardening steel:

When drilling with the smaller sizes of drills, reduce the flute lengths of the drills to the shortest practicable length. This gives the drill maximum rigidity.

Drill jig bushes should be kept as short as possible to enable the shortest drill flute length to be used.

When drilling to depth, the drill should be withdrawn at intervals to minimise clogging and seizing of the flutes. A general guide for deep-hole drilling is to withdraw after penetration to three times the diameter of the drill for the first insertion, after 1½ diameters have been drilled for the second and ¾ diameter for succeeding depths.

When using hand feed, do not let the drill dwell without cutting. Drilling pressure should be uniform and continuous.

For deep-hole drilling the crankshaft-type drill is recommended. This drill has a quick helix angle and a heavy reinforced web to give maximum rigidity. Fig. 3 shows the suggested method of point grinding the reinforced web crankshaft type drill. This is designed to provide cutting edges on the chisel point, thus reducing drilling pressures. Soluble oil coolants are recommended for larger-diameter drilling, whilst tallow or turpentine are most suitable for smaller-diameter work. Table XIII gives drilling speeds and feeds per revolution recommended for normal depth drilling of steels of 70 tons tensile. The speed may be increased by 20 per cent. for the 55–60 tons range, but should be reduced by 20 per cent. for the 80 tons tensile strength.

Tapping

High-speed steel-form relieved-ground thread taps are recommended for high-tensile and austenitic steels. The rake angle or undercut should be increased to the order of 8–10°. The strong tenacious chips given from high-tensile steels call for care in reversing the tap and, to minimise the danger of snipping, the back face of the lands should be radial or slightly undercut to break the chips on reversal. To give the optimum combination of strength of tap with effective chip space, two-flute taps are suggested for the very small sizes, with three-flute up to ½ in. or ⅝ in., depending on the depth of hole. The tapping of difficult materials should not be attempted with a drilled hole giving a full thread. A maximum of 75 per cent. full thread should be used to avoid overloading the tap. When tapping long through holes and blind holes in high-tensile and austenitic work-hardening steels, the use of serial taps is particularly desirable. These have the taper and second taps undersize, and Fig. 4 shows the balanced distribution of work when using serial taps. For repetition through-hole tapping, optimum results are obtained with spiral-point or gun-nosed taps. A good flow of sulphurised cutting oil is recommended for larger taps, with mixtures of

white lead and tallow in equal parts suitable for small-diameter working. Suggested speeds for the machine tapping of through holes, employing gun-nosed taps, are:

60 tons per square inch tensile strength .	. 35–40 ft. per minute.
70 tons per square inch tensile strength .	. 25–35 ft. per minute.
80 tons per square inch tensile strength .	. 15–20 ft. per minute.

For blind-hole tapping these speeds should be reduced by 50 per cent.

J. W.

ALUMINIUM AND ITS ALLOYS

ALUMINIUM is now produced in such quantity that in terms of volume it ranks second only to steel amongst the industrial metals. This position is all the more remarkable when it is recalled that the metal itself has been known only about 130 years and, indeed, the industrial history of aluminium did not begin until 1886, when Paul Heroult in France and Charles Martin Hall in the U.S.A. independently discovered that it could be produced by passing an electric current through a bath of molten cryolite in which aluminium oxide is dissolved.

In the very early days of the industry, there was considerable difficulty in finding an adequate outlet for the metal, but as its unique combination of properties and the possibilities of varying them by alloying with other metals became known, the demand increased, so that production rose to a great extent and the price fell.

The growing importance of air transport has been a main cause of the rapid rise of the aluminium industry—and it has itself been made possible by the achievements of the industry in producing light alloys of ever-improved quality, strength, and consistency.

As is shown by the following table, aluminium is the most abundant metal in the earth's crust, but it is always combined with other elements.

THE PRINCIPAL ELEMENTS IN THE EARTH'S CRUST (PER CENT.)

Oxygen	47·33	Calcium	3·47
Silicon	27·74	Sodium	2·46
Aluminium	7·85	Magnesium	2·34
Iron	4·50		

Other common metals, such as copper, lead, zinc, nickel, chromium, jointly account for less than 4 per cent.

Aluminium is an important constituent of nearly all common rocks, except sandstone and limestone, but the only commercial source of the metal is bauxite, a hydrated form of alumina often produced by the weathering of igneous rocks. Bauxite is readily purified to give alumina or aluminium oxide from which the metal is extracted by electrolysis.

Bauxite is widely distributed in many parts of the world, but deposits of the requisite high purity are found in comparatively few places. The mineral takes its name from Les Baux, in southern France, where it was originally mined, but it was not long before deposits were found in the United States, Italy, Istrari and Dalmatia, Greece, and Hungary. Later, important deposits were found in the British and Dutch Guianas, Brazil, on the Gold Coast, the British and Dutch East Indies, and Malaya. Other deposits occur in Australia, India, and

parts of Russia, and most recently the ore has been found in the West Indies.

The most important condition of the economic production of aluminium is that electricity for the reduction process should be available cheaply and in plenty. Aluminium reduction plants are therefore situated near sources of hydroelectric power, and the production of metallic aluminium is not confined to the countries where bauxite is mined.

Aluminium is available in several purities, varying from commercial purity (99 per cent. minimum) to 99·99 per cent. purity, the chief impurities being silicon and iron. The mechanical strength of the unalloyed metal is low, the minimum ultimate tensile strength ranging from $4\frac{1}{2}$ to about 9 tons per square inch, according to the amount of cold working the metal has undergone. By alloying and suitable heat-treatment, materials may be obtained with minimum ultimate tensile strengths up to 38 tons per square inch.

The word "aluminium," in fact, to-day is frequently used to cover both the metal itself (of varying degrees of purity) and the several families of aluminium alloys. In the United States the word "aluminum" has been generally adopted to cover any aluminium-base material, and the same tendency is evident in Great Britain.

Main Groups of Materials

Cast products may be in the form of sand castings, gravity or pressure die castings. The choice between these forms will depend upon the size and intricacy of the product and the number of castings to be produced, and also upon the composition of the aluminium alloy used. The mechanical properties of certain casting alloys may be improved by heat-treatment.

Wrought materials are produced by the mechanical working of cast ingots or billets, as a result of which the homogeneity and properties show a considerable improvement over those of cast metal. Working may include hot and cold rolling into sheet and strip, extrusion, forging by hammer or press, and drawing into tubes and wire. The wrought materials are therefore available in the forms of plate, sheet and strip, foil, extruded sections, bars for machining or forging, forgings, tubes, and wire.

The wrought materials are subdivided into two main groups, namely, those in which mechanical properties are developed by cold working, and those in which these properties are developed by heat-treatment; the former do not respond to heat-treatment, and are classed as non-heat-treatable alloys.

Cold working of aluminium and its alloys, such as by rolling, drawing, pressing or stamping, increases their tensile strength and at the same time reduces ductility. The mechanical properties of work-hardened alloys thus depend on the degree of working, and many alloys can be obtained in various tempers, ranging from soft to hard.

Heat-treatment

Both wrought and cast materials may be heat-treated in one or two stages, according to the mechanical properties required from the material concerned.

Wrought Alloys.—The first stage is a solution treatment followed by natural ageing. Solution treatment consists of heating the alloy in an air furnace or a salt bath to about 500° C.—the exact temperature depends upon alloy composition—and then quenching it from that temperature in water or, less commonly, in oil or air blast. After this the alloy spontaneously grows in strength at room temperature over four or five days; at the end of the period its properties are stable at a higher level than before treatment. In this condition the alloy is referred to as "single heat-treated." As natural ageing follows the heating and quenching process unless some other treatment is given, it has also become common practice to describe this type of treatment, including the natural ageing, as simply "solution treatment."

Certain alloys do not attain their full strengths on natural ageing, but are artificially aged by means of "precipitation treatment." After quenching as before, the material is heated to a temperature between 120° and 200° C. for periods of ten to twenty hours—the exact temperature and period depending largely upon the alloy—and then allowed to cool in air. The properties are stable at the end of this treatment, and the material is described as " double heat-treated," or, more commonly, as "fully heat-treated."

Cast Alloys.—Heat-treatment practice for cast alloys differs from that described above, in that a moderate increase in strength in some alloys is obtained by a precipitation treatment without previous solution treatment. Furthermore, marked natural ageing does not occur in the casting alloys (with one exception), and the full mechanical properties are only obtained by a subsequent precipitation treatment. On the other hand, certain alloys are subjected to solution heat-treatment only, as in this condition maximum ductility is obtained, and since natural age-hardening does not follow, this condition is maintained.

Heat-treatable material is usually supplied to the user after heat-treatment, and therefore he need not be concerned with the details of the process, but he does require to ensure that subsequent operations do not adversely affect the properties obtained by heat-treatment. Two points may be noted. First, that when certain heat-treated alloys are subsequently welded or annealed, their properties may be largely restored by a second process of heat-treatment—this applies also to all heat-treated cast alloys; secondly, that the heat-treatable wrought alloys can be cold worked within the two hours immediately following the solution-treatment quench—that is, before appreciable ageing has occurred. Natural ageing is inhibited by refrigeration at sub-zero temperatures down to − 20° C.

On both these points it is imperative to consult the supplier of the material regarding the exact temperatures and heating periods for each alloy.

Specifications

The large number of aluminium alloys produced to manufacturers' schedules is sometimes confusing to those responsible for choosing material.

A few aluminium alloys were included in the original General Engineering

PROPERTIES OF ALUMINIUM AND ALUMINIUM ALLOYS

(Minima required by B.S. General Engineering Specifications)

TABLE I —CASTINGS—B.S 1490

Alloy Designation		Condition		0·1 *per cent Proof Stress** (*tons per sq in*)	*Ultimate Tensile Strength* (*tons per sq in*)	*Elongation on 2 in* (*per cent*)
LM1–M		As cast	S C	(5·5) (7·0)	8·0 10·0	— —
LM2–M		As cast	S C	(4·5) —	8·0 9·5	— —
LM3–M		As cast	S	(5·0)	9·0	—
LM4–M		As cast	S C	(4·0) (4·5)	9·0 10·0	2·0 2·0
LM5–M		As cast	S C	(5·0) (5·0)	9·0 11·0	3·0 5·0
LM6–M		As cast	S C	(3·5) (4·5)	10·5 12·0	5·0 7·0
LM7–	M	As cast	S C	(4·0) (4·5)	9·0 10·0	2·0 2·0
	P	Precipitation heat-treated	S C	(7·0) (8·0)	10·0 12·5	2·0 3·0
LM8–	W	Solution heat-treated	S C	(7·0) (7·0)	11·0 15·0	2·5 5·0
	WP	Fully heat-treated	S C	(1[illegible]·0) (13·0)	15·0 17·0	— 2·5
LM9–	P	Precipitation heat-treated	S C	(7·0) (8·5)	11·0 15·0	1·5 2·0
	WP	Solution heat-treated	S C	(13·0) (16·0)	15·5 19·0	— —
LM10–W		Solution heat-treated	S C	(10·0) (11·0)	18·0 20·0	8·0 12·0
LM11–	W	Solution heat-treated	S C	(8·0) (8·5)	14·0 17·0	7·0 13·0
	WP	Fully heat-treated	S C	(12·0) (12·0)	18·0 20·0	4·0 9·0

Alloy Designation		Condition		0·1 *per cent. Proof Stress** (*tons per sq. in*)	*Ultimate Tensile Strength* (*tons per sq. in*)	*Elongation on 2 in.* (*per cent*)
LM12–WP		Fully heat-treated		Brinell Hardness 100–150		
LM13–	WP	Fully heat-treated	S C	— —	11·0 16·0	— —
	WP (Special)	Specially heat-treated	S C	— —	9·0 13·0	— —
LM14–	M	As cast	S C	(8·5) (10·0)	10·0 12·0	— —
	WP	Fully heat-treated	S C	(13·0) (14·0)	14·0 18·0	— —
	WP (Special	Specially heat-treated	S C	— —	12·0 15·0	— —
LM15–WP		Fully heat-treated	S C	(17·0) (17·0)	18·0 21·0	— —
LM16–	W	Solution heat-treated	S C	(10·0) (10·0)	11·0 13·0	2·0 —
	WP	Fully heat-treated	S C	(11·0) (13·0)	15·0 17·0	— —
LM17–M		As cast	S C	(4·5) (6·0)	12·0 16·0	2·0 3·0
LM18–M		As cast	S C	(3·5) (4·0)	7·5 9·0	3·0 4·0
LM19–W		Solution heat-treated	S C	— —	14·0 17·0	3·0 5·0
LM20–M		As cast	S C	(3·5) (4·0)	10·5 12·0	3·5 5·0

S = Sand Cast. C = Chill Cast. * Figures in parentheses are typical and not minimum.

PROPERTIES OF ALUMINIUM AND ALUMINIUM ALLOYS

(Minima required by B.S. General Engineering Specifications)

TABLE II.—WROUGHT PRODUCTS—B.S. 1470–1476

(Note.—Exact figures depend on form and treatment)

Material Designation	*Condition*	0·1 *per cent. Proof Stress** (*tons per sq. in.*)	*Ultimate Tensile Strength* (*tons per sq. in.*)	*Elongation on 2 in.* (*per cent.*)
1A	O	—	4·0–5·0	35
	H	(7·5)	6·5–8·0	5
	As extruded	—	3·5	30
1B	O	—	4·5–6·0	30
	H	(7·8)	7·0–8·5	5
	As extruded	—	4·0	25
1C	O	(2·0)	5·0–6·5	30
	H	(9·0)	7·0–9·0	3
	As extruded	—	4·0	20
N3	O	(3·0)	6·0–7·5	30
	H	(11·0)	11·5	3
N4	O	(5·0)	9·0–14·0	18
	¼H	11·0–12·0	15·0	5
	As extruded	—	11·0	18
N5	O	6·0–7·0	14·0	18
	¼H	11·0	17·0	8
	As extruded	5·0–6·0	14·0	18
N6	O	8·0	16·0–17·0	18
	¼H	14·0	19·0	8
	As extruded	7·0–8·0	16·0	18
N7	O	9·0	20·0–23·0	18
	As extruded	8·0–9·0	0·02	18
H9	W	5·0	9·0	18
	WP	10·0	12·0	12
H10	W	7·0	12·0–14·0	12–18
	WP	15·0	18·0–19·0	8–10
H14	T	13·5–18·0	24·0–26·0	8–15
H15	W	13·5–18·0	24·0–26·0	8–15
	WP	20·0–26·0	26·0–30·0	6–10
H17	WP	—	22·0	8
H18	WP	—	24·0	6

* Figures in parentheses are typical and not specified minimum values.
Where a range is given, the specified minimum value varies according to the form or size of the material.

series of British Standards, but most of these cover only the older casting alloys. Aircraft Material Specifications of the British Standards Institution and D.T.D. Specifications of the Ministry of Supply cover the aluminium and aluminium alloys used in British aircraft.

More recently the British Standards Institution has produced the new General Engineering Specifications, which follow the same lines as the S.T.A. 7 Schedule and present a full range of alloys for general engineering purposes. In these specifications the system of nomenclature describes the type of material, its form, and condition. British Standard General Engineering series numbers are used in this article.

The wrought materials are arranged in a numerical order corresponding

approximately to increasing strength: each form is indicated by a prefix letter as follows:

Sheet and strip	S	Tubes	T
Plate	P	Welding wire	W
Clad sheet, strip, and plate	C	Wire for rivets	R
Bars, rods, and sections	E	Wire for general purposes	G
Forgings	F		

The grades of commercial aluminium are designated 1A, 1B, and 1C in descending order of purity, and the wrought alloys follow from 2 onwards.

The non-heat-treatable wrought alloys are indicated by the initial letter N. These alloys can be strengthened only by cold working and softened by heating. The tempers in which they may be obtained range from the soft or annealed temper to the fully work-hardened condition.

Temper is indicated by the following symbols:

O = Soft or annealed.	¾H = Three-quarter hard.
¼H = One-quarter hard.	H = Hard.
½H = One-half hard.	M = As manufactured.

The heat-treatable wrought alloys are indicated by the initial letter H, and condition is described by the following suffix symbols:

Annealed	O
As manufactured	M
Solution treated, requiring no precipitation treatment	T
Solution treated, will respond to precipitation treatment	W
Solution treated and precipitation treated	WP

Thus, a single heat-treatment alloy in its strongest condition is indicated by the suffix T and a double-heat treatment alloy by the suffix WP.

The following are examples of the above nomenclature:

"NS5–¼H" denotes non-heat-treatable aluminium wrought alloy No. 5 in the form of sheet or strip, and in the quarter-hard temper. Similarly, "HS10–W" denotes heat-treatable aluminium alloy No. 10 in the form of sheet or strip which has been solution treated (or single heat-treated) and which will respond effectively to precipitation treatment (or full heat-treatment).

PROPERTIES OF ALUMINIUM AND ALUMINIUM ALLOYS

The average physical properties of aluminium and aluminium alloys may be briefly summarised as follows:

	Pure Aluminium	*Aluminium Alloys (according to Composition and Treatment)*
Density (grm./c.c.)	2·70	2·55–2·85
Density (lb./cub. ft.)	1·685	159·5–178·0
Melting-point (° C.)	660	450–650
Thermal conductivity (C.G.S. units)	0·54–0·57	0·3–0·5
Electrical resistivity (microhms/c.c.)	2·65–2·95	3·3–8·5
Specific heat	0·211	0·23

Stresses

Proof Stress.—Aluminium alloys, in common with other non-ferrous materials, do not show a sharply defined yield point during test. The tensile properties determined for these materials are the proof stress, the ultimate tensile stress, and the elongation.

B.S. 18, 1938, defines proof stress as "the stress which is just sufficient to produce under load a non-proportional elongation equal to a specified percentage of the original gauge length."

In this country the elongation specified is usually 0·1 per cent. of the gauge length. The 0·1 per cent. proof stress is "the maximum load per square inch which, when applied to a tensile test piece for 15 seconds (B.S. 18 specified period) and removed, produces a non-proportional elongation of not more than 0·1 per cent. of the gauge length."

Ultimate Tensile Stress.—This is determined for aluminium alloys, as for other metals, by the stress required to break a test piece of standard dimensions in a tensile testing machine. The ultimate tensile stress is obtained by dividing the maximum test load by the original cross-sectional area of the test piece.

Elongation

Elongation, which is a measure of the ductility of the material, is determined as a percentage increase in length of a stated gauge length of the tensile test specimen. The standard gauge length for test pieces for sheet, strip, plate, flat bar, and sections is 2 in. In certain cases a length of $4\sqrt{A}$ is used, where A = cross-sectional area of section.

Specification figures for ultimate tensile stress and elongation, together with some typical values for proof stress, are given in the tables on pages 463 and 464. It is important to emphasise that the specified figures are minima, and that with the wrought material considerably higher values are usually obtained. Users of castings, however, should appreciate that the minimum specified properties may not be obtainable in all parts of a casting.

The tensile properties required by current specifications are shown in Tables I and II.

Elasticity

The mechanical constants for aluminium and the aluminium-base alloys are taken as approximately:

Young's modulus of elasticity (E) . .	9·9–10·5 × 10^6 lb./sq. in.
Torsion modulus (G)	3·5–3·9 × 10^6 lb./sq. in.
Poisson's ratio	0·32–0·34

The elastic modulus of aluminium and its alloys is little more than one-third that of steel, so that the elastic deflection under load is correspondingly greater. In some circumstances this may be a considerable advantage, for instance, when an aluminium structure is loaded under shock conditions, its

greater resilience enables it to absorb more energy than a corresponding steel structure. Also, the effect of applied strains—such as those due to temperature changes—is much less.

Rigidity

The lower value of elastic modulus means that for equal rigidity an aluminium alloy beam must have a greater cross-sectional area than a steel beam. For such applications as long struts or beams, the stiffness, or crippling strength, can be made the same as a steel beam or strut approximately twice the weight, provided it is possible to increase the depth of the beam or the radius of gyration of the strut.

Strength in Compression

For design purposes, the 0·1 per cent. proof stress in compression may be taken as the same as the proof stress in tension, the ductility of many aluminium alloys making it difficult to determine their maximum strengths in compression. The design of short concentrically-loaded struts may be based on the tensile figures, but less compact members in compression should be designed in accordance with suitable column formulæ.

Shear Strength

The ultimate shear stress for aluminium and aluminium alloys may be taken, on average, as about 60 per cent. of the ultimate tensile stress, but in practice the value is often greater than this.

Bearing Strength

Bearing yield strength is that stress which produces a 1 per cent. permanent elongation based on the hole diameter, and it is general practice to consider yield stress as about 1·5 times the tensile proof stress of the material if suitable edge distances are maintained. This factor varies from 1·2 to 1·8 according to the composition and condition of the material.

Fatigue Strength

The form of endurance curve common to most aluminium alloys is similar to that for other non-ferrous metals, and differs from the curve for mild steel, in that the plotted values of S/N in most cases do not become asymptotic even after one hundred million cycles of stress. In many cases the endurance limit may approximate to 30 per cent. of the ultimate tensile strength. Alloy N7, however, with a particularly high ratio between endurance limit and ultimate tensile strength, shows S/N curve characteristics similar in general form to those of mild steel.

Strength at Elevated Temperatures

Aluminium alloys have been specially developed for service at raised temperatures, the first being the Y-alloy, comprising essentially the addition of

about 2 per cent. nickel to the duralumin-type alloys. Other alloys for the same purpose followed, and the range in the General Engineering series includes the casting alloys numbers LM 12, 13, 14, and 15, for pistons in particular, and the wrought alloys H 12, 17, and 18, which are high-strength forging alloys. These materials, in addition to retaining in high degree their mechanical properties at the higher temperatures, also show good recovery at room temperatures—even after prolonged periods at raised temperature.

Atmospheric Exposure

Aluminium and its alloys have in general a high resistance to the effect of atmospheric conditions. This is due to the strong, stable film of oxide that forms on all aluminium surfaces on exposure to air, and reforms with perfect continuity if subsequently ruptured. The oxide film itself is colourless, but exposed structures tend to weather to shades of grey, dependent largely upon the nature and amount of impurities in the atmosphere. Painting is specified only in polluted atmospheres; subsequently, repainting is required less frequently than on other metals, since the re-oxidation of the freshly exposed metal surface prevents the spreading of attack at a chipped or abraded area.

The nature of the resistant oxide film is influenced by the presence of alloying elements, and therefore the durability of aluminium alloys varies to some extent with their composition. The series of aluminium alloys containing magnesium as the main alloying element is notable for immunity to attack in marine atmospheres and in contact with sea-water. Such alloys are therefore specially suitable for hulls of small craft, lifeboats, and parts in the superstructure of ocean-going vessels. The cast aluminium-silicon alloys are also durable under these conditions. The presence of a substantial amount of copper as an alloying element tends to reduce durability, and painting is therefore recommended when copper-containing alloys, both cast and wrought, are to be used out-of-doors.

Aluminium Alloys and Chemicals

Although the aluminium alloys show good resistance to a wide range of chemicals, unalloyed aluminium in various purities is generally considered to be most suitable for the construction of chemical plant. Occasional contact with chemical fumes or reagents is not harmful to most of the alloys. The following gives some indication of the action of common chemicals, but more detailed information relating to specific cases is available.

1. Reagents with no action or very slight action: nitric acid in certain concentrations, acetic acid, ammonia, sulphides, sulphuretted hydrogen, and most organic compounds.

2. Reagents which attack aluminium alloys: most alkalis, carbonates, formic acid, hydrochloric acid and chlorides, hydrofluoric acid and fluorides, sulphuric acid, especially over 20 per cent. concentration by weight.

Alkalis, which possess valuable detergent qualities, may be rendered less harmful to the aluminium alloys by the addition of a small proportion of an

inhibitor such as sodium silicate; for example, washing soda is made completely harmless by this addition.

"Clad" Sheet and Strip

High resistance to corrosion, combined with optimum mechanical properties, is obtained by coating strong alloy sheet with pure aluminium, to give, for example, alloy HC 15. Sheet of this type consists of a core of a heat-treated alloy covered on each side by a thin coating of high-purity aluminium which prevents contact between corrosive agents and the core. It also confers electrolytic protection on the core, even at cut edges and in spots from which the "cladding" has been removed.

The pure aluminium coating is approximately 5 per cent. of the total thickness of the sheet on each side, and is of 99·5 per cent. minimum purity.

MACHINING, PROCESSING, AND FINISHING

All aluminium alloys have good machining properties which improve with the hardness of the material. On the fully heat-treated alloys, very high machining speeds are attained, but the soft alloys are somewhat luggy and require careful attention to tool design. The machining of alloys containing silicon also requires care, since the wear on tool edges is likely to be severe.

Cold Forming

The non-heat-treatable aluminium alloys, like the pure metal, have good cold working properties, but severe cold forming should be done in stages with interstage annealing. The heat-treatable alloys can also be cold-formed within certain limits and in the appropriate conditions.

ANNEALING.—Annealing for further cold work is usually carried out in batch furnaces at temperatures ranging from 320° to 420° C.: heat-treatable alloys should be cooled slowly from the annealing temperature. After cold forming, the heat-treated alloys may be given the final heat-treatment.

The usual cold working operations, such as drawing, pressing, and stamping, are applied to aluminium and its alloys.

Joining

FUSION WELDING.—The usual welding processes for aluminium and its alloys are gas welding, argon arc, carbon arc, and metallic arc welding and atomic hydrogen welding. The inert-gas shielded arc process—e.g. the argon arc—offers the greatest potentialities for easy, rapid, and sound welding. As annealing destroys many of the properties produced by heat-treatment, fusion welding of the heat-treatable alloys, though practicable, can only be recommended if loss of strength is unimportant.

RESISTANCE WELDING.—Owing to their high electrical conductivity, all the wrought aluminium alloys require current densities considerably higher than those used for steels; spot welding is applied very successfully to the high-strength alloys.

RIVETING.—Riveting has long been used as the standard method of joining aluminium sections, and automatic machines maintain a high rate of production on straightforward assemblies. For large-scale structural work, mild-steel rivets, driven hot, may be used for joining the aluminium alloys.

BRAZING AND SOLDERING.—Brazing is being increasingly used, particularly the furnace brazing process for mass-produced assemblies. The usual brazing metal is an alloy of high silicon content, and the application is limited for most purposes to pure aluminium and alloys N3 and H10.

Although soldering is possible by the use of special fluxes, solders, and techniques, its application is restricted to places where there is good mechanical support for the joint and where the surrounding atmosphere is not corrosive. Its chief application is to electrical instruments and connectors.

Extrusion

The process produces, in addition to simple shapes, complex sections which often eliminate further fabrication, and it therefore yields considerable economies in application. Pure aluminium and the wrought alloys are extruded with varying ease according to composition.

Surface Finishing

Mechanical finishing processes include grinding and polishing, sand and shot blasting, scratch-brushing, barrelling, and hammer finishing.

Various chemical processes are available for thickening the natural oxide film, giving some additional protection against corrosion, and forming a good key for paint; the thickened film can also be dyed.

Electroplating solutions and bath conditions are established for the plating of aluminium with copper, brass, zinc, nickel, silver, gold, and certain rare metals. Anodic oxidation is an electrolytic method of thickening the aluminium-oxide film to give maximum protection and to provide a distinctive soft sheen which may be dyed. By the process of electro-brightening, the total reflection factor of super-purity aluminium is raised from 72–74 per cent. to 85 per cent.; the reflectivities of other grades of pure aluminium are correspondingly increased by this process.

Paint systems do not differ from those for other metals, and may consist of one coat or more. Mechanical roughening or chemical pretreatment is necessary to secure paint adhesion. Primers for aluminium often incorporate an inhibitor such as zinc chromate, and primers containing an etchant which eliminates pretreatment are now available. Aluminium paint has specially good protective qualities, derived largely from its flake or leaf formation.

Stoving finishes are successfully applied by the usual methods within the temperature limits applicable to the material. Some vitreous enamels have been developed with firing temperatures that make their application practicable, but the difficulties are still considerable.

E. G. W.

COPPER AND ITS ALLOYS

THE outstanding characteristics of copper which determine its extensive engineering applications are its high electrical and thermal conductivity, its ready workability, and its relatively high resistance to corrosion. By alloying suitable metals with the copper, greatly increased strength can be obtained, while the high workability and corrosion resistance can be retained or improved. A wide range of copper alloys also has excellent properties as bearings. These improvements by alloying, however, are generally obtained only at the expense of a severe decrease in conductivity (Fig. 1), though even in this respect copper alloys are still superior to alloys of other common metals having comparable strength.

In view of this general relationship between strength and conductivity it is convenient to consider copper products in three groups:

(1) Pure copper and the commercial coppers in which high conductivity and extreme workability are the most important properties.

(2) Copper with small additions of other metals selected to give an appreciable increase in strength while retaining the highest possible percentage of conductivity.

(3) Copper alloys in which conductivity is less important than other properties, such as high strength or good bearing properties, combined with good castability.

PURE COPPER AND COMMERCIAL COPPERS

Copper is difficult to prepare on a commercial scale in a wrought form in super-pure condition, and the various grades of commercial coppers available differ in respect of the kind and amount of minor constituents which they contain. Some of these constituents, such as oxygen, bismuth, and lead, are impurities present from the raw materials or absorbed during melting and casting; others, such as phosphorus, arsenic, and silver are introduced to secure some specific effect.

Properties of Pure Copper

The most important property of high-purity copper is its excellent electrical conductivity which gives it its extensive application in electrical engineering. According to the International Annealed Copper Standard, the specific resistance of pure annealed copper is 1·7241 microhms per sq. cm. per cm., and its

TABLE I.—MECHANICAL PROPERTIES OF PURE COPPER

	Cast	Wrought Annealed		Hard Drawn
	20° C.	20° C.	250° C.	20° C.
U.T.S. (tons per sq. in.)	10–11	14·0–14·5	10·2	28–30
Elongation (per cent.)	45	60	50	3
Reduction of area	57	70	50	—
Fatigue limit (tons per sq. in.)	± 6·5	± 5·5	—	± 6·5

conductivity is therefore 0·58001 reciprocal microhms per sq. cm. per cm. The conductivity of any copper product is defined as a percentage of this value. On this scale, the purest copper at present obtainable, oxygen-free high-conductivity copper (O.F.H.C.), has a conductivity of 103 as fully annealed, 98–100 as cold worked, but only 97–99 as cast.

The thermal conductivity of pure copper is also very high, over 0·92 C.G.S. units, making it very suitable for applications in which heat transfer is involved.

Owing to the combination of high thermal and electrical conductivity, O.F.H.C. copper requires very heavy currents for arc welding, but it is suitable for gas welding, while oxygen-bearing coppers, discussed later, give trouble in this respect. Super-pure copper, such as O.F.H.C., is relatively weak but extremely ductile (Table I) and capable of undergoing very severe cold-drawing operations. Under severe cold work, however, this material may develop marked directional properties, and careful control of fabrication procedures and of annealing treatments is necessary to avoid this. The material can be hot worked over a wider temperature range than can less-pure grades.

Pure copper has a good resistance to most chemicals except strong mineral acids and ammonia, and this property is not seriously affected by impurities. Its corrosion resistance, coupled with good malleability, weldability, and high thermal conductivity, are made use of in chemical engineering, especially for applications in which heat transfer is involved. In the atmosphere, copper develops an attractive green patina which protects it from further attack, hence its extensive use in building. Its high resistance to soil corrosion renders it very suitable for piping gas or water underground.

Properties of Commercial Coppers

Commercial grades of copper other than O.F.H.C. contain various impurities and minor constituents. Impurities soluble in solid copper reduce conductivity, but have little effect on working or mechanical properties, e.g. bismuth, lead, copper oxide, have little effect on conductivity, but decrease ductility. Bismuth and lead cause hot-shortness.

The distinctive properties, and the applications of the various grades of commercial other than O.F.H.C. copper, are summarised below:

Cathode Copper.—This is a high-purity electrolytically refined copper, but

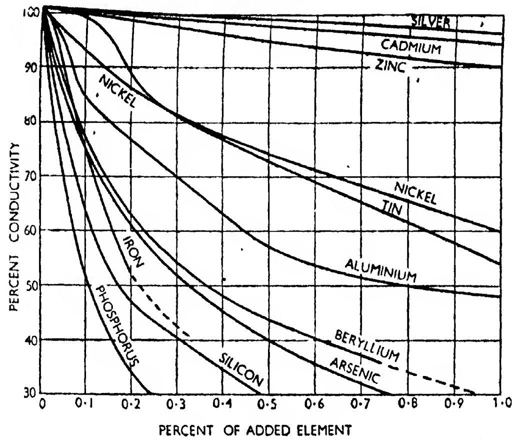


FIG. 1.—EFFECTS OF ADDED ELEMENTS ON THE ELECTRICAL CONDUCTIVITY OF COPPER (*Copper Development Association*)

it is too brittle for fabrication due to the presence of occluded hydrogen. It is remelted to give electrolytic tough-pitch copper, and is used extensively for high-conductivity castings and in alloy making.

Tough-pitch High-conductivity Coppers.—These are high-purity coppers, but they contain from 0·02 to 0·04 per cent. oxygen. They are produced either by remelting cathode copper in a normal atmosphere or by fire-refining high-grade blister copper. The correct pitch is obtained when the exposed surface of a cast ingot sets level. If it rises the metal contains excess hydrogen, i.e. oxygen content is too low. If the surface sinks, the oxygen content is too high; in either case ductility will be less than that of correct "tough-pitch" copper.

High-conductivity coppers are used mainly in electrical engineering, but also where high thermal conductivity is required, as in heat interchangers and other chemical plant.

Silver-bearing H.C Copper.—The addition of 0·08–0·1 per cent. silver raises the softening temperature of cold-worked H.C. copper to 300–350° C., with very little loss of conductivity. This material is used extensively for electrical parts which have to be hot-tinned or soldered while retaining their extra hardness due to cold work.

Ordinary Tough-pitch Copper.—This material is the ordinary (oxygen-bearing) copper of commerce, supplied in all the usual fabricated forms. Its conductivity, due to soluble impurities, is appreciably below that of H.C. grades, but it is suitable for many applications where very high conductivity is not essential. The material must not be heated in a reducing atmosphere, however, or cracking will occur due to evolution of steam (gassing).

Phosphorus Deoxidised Copper.—This is ordinary fire-refined copper, deoxidised with phosphorus, and containing a residuum of 0·03–0·04 per cent. of this element. Conductivity is low compared with O.F.H.C., due to the dissolved phosphorus, but the material is not subject to "gassing," and readily sheds its scale on heating. It is used extensively where welding is required, and for tubes for plumbing and general purposes.

Arsenical Coppers.—Arsenic in amounts of 0·3–0·5 per cent. is added to deoxidised and to tough-pitch coppers for improving mechanical properties at 200–300° C., resistance to scaling, and resistance to chemical attack. Arsenical coppers are used mainly for locomotive fire-box plates and stay rods, for piping systems, and chemical plant. Conductivity is relatively low, since the arsenic is in solution.

Free-cutting Coppers.—Small amounts of tellurium, selenium, and lead are added to high-conductivity and other grades of copper to improve the machinability. Tellurium also raises the softening temperature, and may be used in place of silver in H.C. copper for this purpose. Lead is less satisfactory than tellurium or selenium for improving machinability due to its bad effect on hot-working properties.

COPPER ALLOYS WHICH COMBINE HIGH CONDUCTIVITY WITH GOOD MECHANICAL PROPERTIES

The two types of alloys available to meet these requirements are solution-hardened alloys and alloys hardened by a dispersed phase.

Bismuth and other impurities in general are less harmful in tough-pitch coppers than in oxygen-free coppers.

Solution-hardened Alloys

In this group increased strength is obtained by solution of the alloying element in copper. Since elements in solid solution reduce conductivity rapidly, cadmium and tin are used; small amounts of these give a rapid increase in strength for a relatively slight loss in conductivity.

Cadmium copper contains 0·6–1·0 per cent. cadmium and has 95 per cent. conductivity with a tensile strength of 18 tons per square inch as annealed, 82 per cent. conductivity with 45 tons per square inch as cold drawn. Post Office bronze contains 0·5–1·5 per cent. tin, with small amounts of suitable deoxidants such as cadmium or zinc (not phosphorus). These give 18–50 tons per square inch, according to the amount of cold work to which they are subjected, with 60–45 per cent. conductivity.

Alloys Hardened by a Dispersed Phase

In alloys of this group the solubility of the added metal decreases with temperature, becoming very low at ordinary air temperature. Such alloys can be heat-treated at a temperature near to their freezing-points to take the second constituent into solution. If quenched from this treatment, and re-heated at some suitable intermediate temperature, most of the second phase is precipitated from solution in a fine state of dispersion. This causes considerable hardening and strengthening accompanied by an increase in conductivity.

The chief alloys of this class are beryllium-copper (2 per cent. Be) which, when heavily cold-worked and fully heat-treated, will give 75–100 tons per square inch tensile strength, limit of proportionality 50 tons per square inch, elongation 4 per cent., conductivity 24 per cent. By a compromise, heat-treatment

conductivity of 35 per cent. can be obtained.

Beryllium-copper is used extensively for springs, flexible bellows, Bourdon tubes, non-sparking tools, and for welding electrodes, and springs which have to carry electric current.

Chromium-copper is used where high thermal conductivity is required with high strength, e.g. cylinder heads in I.C. engines, and for welding electrodes.

Copper hardened with about 1 per cent. Ni_2Si is used for locomotive fire-boxes; it has good thermal conductivity, retains its strength well at elevated temperatures, and has good resistance to oxidation and scaling. Copper containing 3 per cent. Ni_2Si in the form of forgings has a tensile strength of 43 tons per square inch with 20 per cent. elongation and conductivity of 41 per cent. I.A.C.S. after suitable heat-treatment.

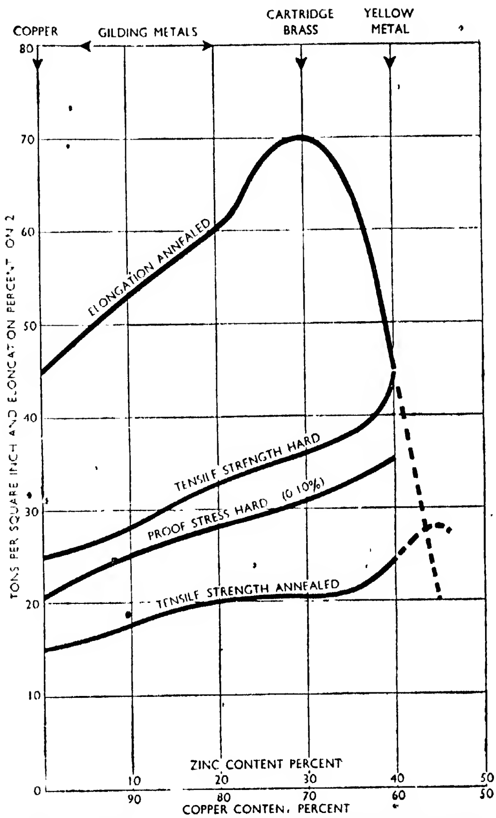


FIG. 2.—COMPARATIVE MECHANICAL PROPERTIES OF WROUGHT COPPER-ZINC ALLOYS (*Copper Development Association*)

BRASSES, BRONZES, AND OTHER COPPER ALLOYS IN WHICH CONDUCTIVITY IS LESS IMPORTANT THAN OTHER PROPERTIES

The properties of copper-base alloys in this class depend on two main features:

(*a*) Their structural character, which determines mechanical and working properties and machinability.

(*b*) Intrinsic effects of the alloying elements, which determine corrosion resistance, bearing properties, heat resistance, weldability, etc.

There are three main groups: (1) Alpha cold-working alloys, (2) Beta and

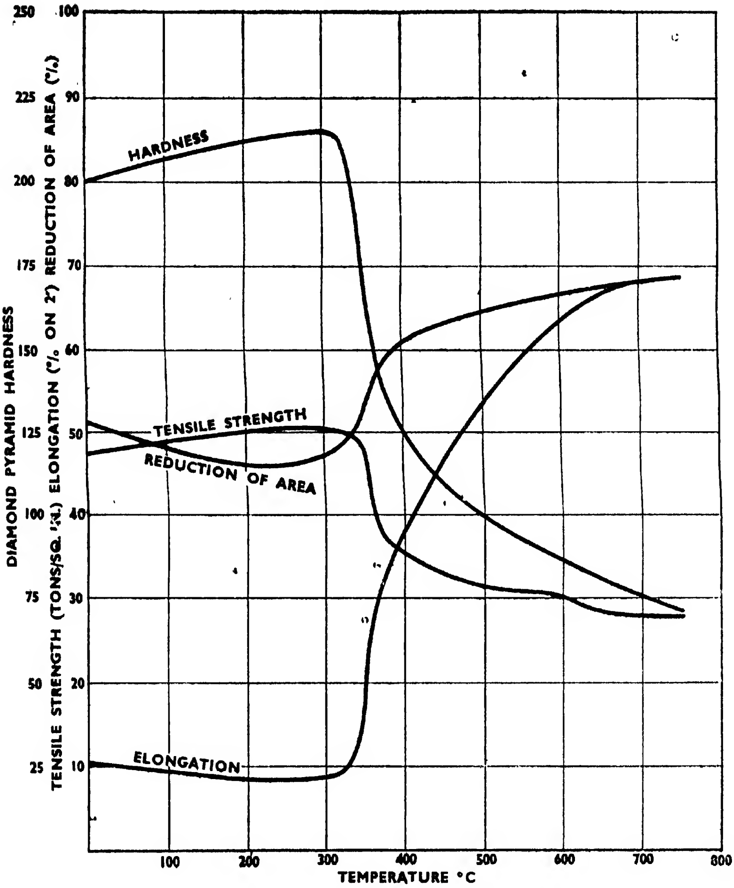


FIG. 3.—EFFECT OF ANNEALING ON MECHANICAL PROPERTIES OF A COLD-WORKED 7 PER CENT. ALUMINIUM BRONZE (*Copper Development Association*)

Alpha + Beta hot-working alloys, (3) alloys with a dispersed phase, used chiefly as castings.

Alpha Solid Solutions—Cold-working Alloys

In an Alpha alloy the alloying elements are completely in solution in the copper; these alloys therefore are structurally homogeneous solid solutions: they are ductile and malleable when cold, but appreciably stronger than pure copper. Typical Alpha alloys are brasses containing up to 36 per cent. zinc, wrought phosphor bronzes, all cupro-nickels, aluminium bronzes containing up

TABLE II.—PROPERTIES OF TYPICAL COMMERCIAL COPPER ALLOYS

Alloy Name	*Composition percentages*	*Wrought Annealed*		*Cold Worked 50 per cent.*	
		U.T.S. tons per sq. in.	*Elongation per cent. on 2 in.*	*U.T.S. tons per sq. in.*	*Elongation per cent. on 2 in.*
Copper-nickel	20 Ni	23	—	34	3
Copper-nickel	30 Ni	25	—	39	3
80/20 Brass	20 Zn	20	60	35	5
Cartridge brass	30 Zn	21	70	40	4
Admiralty brass	29 Zn, 1 Sn	23	67	44	4
Phosphor bronze	5 Sn, 0·1 P	20	60	43	10
Phosphor bronze	10 Sn, 0·05 P	27	70	60	10
Aluminium bronze	7·5 Al	30	65	60	10
Nickel silver	30 Ni, 8 Zn	26	35	42	6
Nickel silver	30 Zn, 5 Ni	23	70	44	4
Silicon bronze	3 Si, 1 Mn	27	70	50	3

to 7 per cent. aluminium, and certain nickel silvers. The strength of an Alpha alloy generally increases with alloy content to the limit of solubility, but elongation reaches a maximum at a lower concentration (Fig. 2).

The mechanical properties of Alpha alloys, like pure copper, can be varied over a wide range by cold work and by subsequent annealing. In general, Alpha alloys containing aluminium, tin, or silicon, respond better to hardening by cold work than do those containing zinc or nickel. Hard-worked phosphor bronzes have good elastic properties and are used extensively as springs.

The effects of annealing on a cold-worked Alpha alloy are shown in Fig. 3. At low temperatures little change occurs; then, over some critical temperature range, hardness and strength fall rapidly while ductility increases. These changes are caused by the recrystallisation of the distorted cold-worked structure. Annealing at higher temperatures causes a further slight fall in strength properties due to growth of the recrystallised grains. At temperatures far above the recrystallisation range, elongation also falls due to excessive grain growth. Due to this coarse-grain effect, any subsequent working operations will give material with a poor surface quality. The annealing temperature must therefore be closely controlled. The critical range for softening and recrystallisation is lowered by increased amounts of cold work, by increased time of annealing, or by decreased initial grain size.

The softening range also varies according to the constituents of the alloys. Thus, for an annealing time of 1 hour 70/30 brass softens at 230–330° C., silicon bronze at 330–400° C., phosphor bronze at 350–400° C., nickel silver (15 per cent. zinc, 20 per cent. nickel) at 450–500° C., and 70/30 cupro-nickel at 600–650° C. The softening range of cold-worked metals and alloys is of great practical importance in determining their suitability for service at elevated temperatures. In general, alloys with high recrystallisation temperatures retain their strength at high temperatures. Thus cupro-nickels are the best of the

TABLE III.—PROPERTIES OF ALPHA-BETA AND BETA ALLOYS

Alloy	*Composition percentages*	*U.T.S. tons per sq. in.*	*Elongation per cent. on 2 in.*	*B.H.N.*	*Structure*
Muntz metal	40 Zn	26	50	70–80	$\alpha + \beta$
Aluminium bronze	10 Al	40	12–24	130–160	$\alpha + \beta$
Superston	10 Al, 5 Fe, 5 Ni	45–55	15–25	180–230	β + Fe
Beta brass	48 Zn	29	12	—	β
Manganese bronze	39 Zn, 0·5 Mn, 0·5 Fe, 2 Al	28–30	25–40	100–120	$\alpha + \beta$
Nickel brass	40 Zn, 16 Ni	40	28	140	$\alpha + \beta$

copper alloys, but aluminium bronzes and phosphor bronzes are both superior to brasses.

Typical mechanical properties of some of the most widely used Alpha alloys are given in Table II. These alloys find applications as sheet, strip, wire, drawn rod, drawn tubes, etc.

Beta and Alpha-Beta Alloys—Hot-working Alloys

In most of the commercial copper-base alloy systems, e.g. copper-zinc, copper-aluminium, and copper-tin, when the alloying element is in excess of that which can be dissolved in copper, a new-phase Beta is formed by the excess solute giving an alloy consisting of Alpha-Beta. As the amount of alloying element increases, so the amount of Beta increases and the amount of Alpha decreases, until with some critical concentration the alloy becomes entirely Beta. The Beta is a body-centred structure (similar to iron), and is harder and tougher than the Alpha phase, but less ductile when cold. At red heat, however, Beta becomes very malleable and ductile, hence Beta and Alpha-Beta alloys are generally fabricated by hot forging, hot rolling or extrusion. The alloys are also used as castings.

The most important alloys of this class are the Alpha-Beta brasses, and the high-tensile brasses, or as they are commonly but quite erroneously called manganese bronzes. These are Alpha-Beta or Beta brasses with other additions. The manganese is often present only in the amount required for deoxidation, but may be up to 3 per cent. Other additions used are tin, aluminium, silicon, iron, and nickel. The amounts added must be calculated carefully with regard to their zinc-replacing power, and the zinc content modified accordingly to preserve the Alpha-Beta or Beta structure. When such alloys are intended for fabrication, it is essential to avoid the appearance of the brittle γ phase. The approximate zinc-replacing power of the common additions are Si = 7, Sn = 2, Fe = 0·9, Ni = 0·8, Mn = 0·5. Typical mechanical properties of Alpha-Beta and Beta alloys are given in Table III.

Alloys Containing Dispersed Phase—Castings

In this group of alloys the structure consists of Alpha, Alpha-Beta, or Beta with an additional phase present as dispersed particles or as films around the

grain boundaries. These additional constituents are generally hard and brittle intermetallic compounds, e.g. Cu_3P (present in phosphorus bearing bronzes), Cu_4Sn, the Delta phase of the casting bronzes. Such constituents have a hardening and embrittling action. Lead may also be present as an additional dispersed phase, but this is soft and malleable, and is added either to improve machinability (0·5–2 per cent.), to improve bearing properties in tin bronzes (5–20 per cent.), or to improve pressure tightness in gunmetals (2–5 per cent.). Alloys of this group have neither the cold-working properties of the Alpha type nor the hot-working characteristics of the Beta and Alpha-Beta types. They are employed as castings (Table IV), in which high ductility is not necessary, but in which some special property may be obtained by the additional dispersed phase, e.g. the wear resistance of bronzes containing Cu_4Sn (Delta) is very high.

Certain alloys of this class containing relatively small amounts of the additional phase retain sufficient ductility to be fabricated and used in the wrought condition; e.g. wrought silicon-iron bronzes contain particles of iron; cold-drawn phosphor bronze (8 per cent. tin, 0·02–0·4 per cent. phosphorus), containing particles of Cu_3P, is used for bearing sleeves.

Castings are generally more brittle and harder than wrought alloys of similar composition, due to non-equilibrium structures, inclusions and casting defects.

Copper alloys used as castings differ in structure and properties from wrought alloys due to the following effects:

(*a*) The Alpha-solid solution is always cored, i.e. it is richer in copper at the centre of the grains than at the boundaries.

(*b*) The second phase, whether Beta or a hard constituent such as Cu_3P, occurs at lower concentration of the alloying element than in the same alloy in the wrought annealed condition.

(*c*) Alpha-Beta alloys have a coarser, needle-like structure known as the Widmanstätten, which is more brittle than the equiaxed structure of wrought Alpha-Beta alloys.

(*d*) Since high ductility is not required in castings, greater hardness can be obtained by using alloys containing relatively large amounts of dispersed hard, brittle phases such as Cu_4Sn present in cast gunmetals, and Cu_3P present in hard-bearing bronzes.

(*e*) The phases present in a cast alloy may differ from those present in the wrought annealed condition, e.g. the tough Beta phase of aluminium bronze containing about 10 per cent. of aluminium decomposes when cooled slowly (as in large batches), to give a brittle Alpha-Gamma constituent. The Beta phase can be retained by additions of iron or nickel which prevent the self-annealing of the Beta, or it can be restored by heat-treatment.

(*f*) Structures and properties may vary in a given casting according to the rate of cooling, e.g. chill-cast gunmetals and phosphor bronzes contain more of the brittle Alpha-Delta constituent than do slowly cooled sand castings. Therefore, other things being equal, chill castings in these alloys are harder and

TABLE IV.—MECHANICAL PROPERTIES OF CAST COPPER ALLOYS

Type	*Alloying Elements percentages*	*Method of Castings*	*U.T.S. tons per sq. in.*	*El. per cent.*	*B.H.N.*
Cored α	Brass, Zn 30	Chill	17	58	55
Cored α	Brass, Zn 30	Sand	15	37	61
Cored α	Bronze, Sn 5	Chill	18	50	80
Cored α	Bronze, Sn 5	Sand	16	40	60
Cored α	Herculoy, Si 3, Sn 5, Zn 1·5	Sand	24	70	—
Cored α	Aluminium bronze, Al 5	Sand or chill	18	60–70	—
Cored α	Copper nickel, Ni 20	Chill	16	21	59
Cored α	Nickel silver, Ni 14, Zn 8, Sn 4	Sand	22	18	—
Cored α	Nickel silver, Ni 20, Zn 20		20	30	65–85
Cored α + Pb	Copper lead, Pb 30, Sn 1, Ni 1	Lined into steel shells	5	—	20–30
α + β	Zn 40–45	Sand	18–20	30–6	70–115
α + β	Aluminium bronze, Al 8–10	Sand	31–32	70–20	—
α + β	Zn 40, Mn-0·7, Al 0·7	Sand	30	30	—
α + β	Bronze—Zn 39, Fe 1, Sn 1, Mn 3	Sand	36	17	140
α + β + Fe	Complex Al. Bronze: Al 8–11, Fe 3, Ni 3	Sand or chill	30	20	—
α + β + Fe	Complex Al. Bronze: Al 8–10·5, Fe 1·5–3·0	Chill	35	35	
β	Mn. Bronze, Zn 40, Al 2·7, Mn 2, Fe 1	Sand	44	20	140
β + Fe	Superston, Al 10, Ni 5, Fe 5		42	15–20	160–180
α + (α + δ)	A.G.M., Sn 10, Zn 2	Sand	18–20	20–40	70–80
		Chill	18–22	5–10	100–120
α + (α + δ + Cu_3P)	Phosp. bronze, Sn 11, P 0·3	Sand	10–16	5–10	90–100
		Chill	24–26	10–20	120
		Centrifugal	20–24	5–10	120
α	Everdur, Si 4·5, Mn 1	Sand	22–28	19–28	100–110
α + Fe	P.M.G., Si 4, Fe 2, Zn 2, Mn 5	Sand	18–24	10–20	90–110

more brittle than sand castings. They will have higher yield points, but lower ductility and generally slightly higher tensile strength.

(*g*) The properties of castings (and of ingots intended for fabrication) can be seriously affected by defects due to unsuitable melting or casting technique. The chief types of defect are:

Shrinkage Porosity.—This occurs as finely distributed intercrystalline fissures in alloys having a wide freezing range, e.g. gunmetals, phosphor bronzes, or as coarse internal pipes or cavities in alloys having a narrow freezing range, e.g. manganese bronzes, aluminium bronzes, brasses. It can be minimised in chill-cast bronzes by using slow top-pouring through a suitable tundish, and in sand castings by the use of suitable feeder-heads and correct design of gating.

Oxide Inclusions.—These occur most objectionably in aluminium bronze and other alloys containing aluminium, to a less extent in brasses, gunmetals, and incorrectly deoxidised tin bronzes. In bronzes containing aluminium, their harmful effects can be avoided by the use of non-turbulent casting by the

Durville process. In tin-bronzes, copper-nickel alloys, gunmetals, and brass oxides can be eliminated by correct deoxidation treatment before casting.

Gas Porosity.—This defect occurs most commonly in the tin-bronze group of alloys and in copper-nickel alloys. It can be avoided by correct treatment of the metal, e.g. with suitable oxidising fluxes, during melting, and correct treatment of the moulds before casting.

Inverse Segregation.—This occurs in the tin-bronze group of alloys as a brittle surface layer of Alpha-Delta constituent which seriously impairs machining operations and ruins working properties. It is most commonly caused by high gas content in the metal, and can be avoided by suitable degassing treatment as mentioned above.

The mechanical properties of castings are in general inferior to those of wrought alloys for the reasons outlined above. Castings are, however, superior with regard to hardness and rigidity. Typical mechanical properties of some common alloys used as castings are given in Table IV.

Machinability of Copper-base Alloys

Machinability varies with the structure of the alloy. Alpha alloys are too soft and ductile to be readily machinable; the metal tends to work and distort, and needs a good supply of a suitable lubricant. The tin bronzes and silicon bronzes are, however, better than brasses and cupro-nickels, due to their lower plasticity.

Alpha-Beta alloys, being tougher and less ductile than Alpha alloys, machine more readily, giving a shorter chip. The Alpha-(Alpha-Delta) gunmetals and bronzes are similar to the Alpha-Beta alloys in this respect.

The most readily machinable alloys are those containing a dispersed phase, and for this purpose lead is commonly added both to Alpha and Alpha-Beta types to give good machinability, e.g. 1–3 per cent. lead in free-cutting brass, 1–2 per cent. lead in bronzes. Tellurium ($\frac{1}{2}$–1 per cent.) can be used instead of lead, particularly in hot-working alloys. These materials give a very short chip, are in some measure self-lubricating, and can be machined at high speeds.

Bearing Properties and Wear Resistance

Bearing properties are related to structure, but the nature of the alloying constituents also has an important effect, tin, lead, and phosphorus being the most useful alloying elements. Alpha-type alloys are generally inferior to duplex Alpha-Beta, Alpha-(Alpha-Delta), or Alpha + lead types, but Alpha bronzes, or bronzes consisting of Alpha with traces of Cu_3P are used for lightly loaded bearings in I.C. engines.

The chief types of bearings for heavy loads and wear resistance are bronzes or gunmetals of the Alpha-(Alpha-Delta) or Alpha-(Alpha-Delta-Cu_3P) types. These have high compressive strength, high wear resistance, and low coefficients of friction. Aluminium bronzes and manganese bronzes (Alpha-Beta types) are occasionally used, but are inferior to the tin bronzes.

When extreme hardness and resistance to wear are required, but only

compressive stresses have to be endured, high tin contents (14–20 per cent.) are used with or without 0·1–1 per cent. of phosphorus. When more toughness and higher fatigue strength is needed, as in gears, wormwheels, etc., lower tin contents are used, e.g. 12–13 per cent. tin with 0·3 per cent. phosphorus, 10 per cent. tin with 0·5 per cent. phosphorus, or 10 per cent. tin with 2 per cent. zinc.

When alignment is imperfect or when high speeds have to be endured, an appreciable lead content is advantageous. The copper/tin/lead series of alloys gives an extremely wide range of properties by variation of the lead/tin ratio, e.g. 10 per cent. tin with 10 per cent. lead gives a hard strong alloy suitable for mill bearings, while at the other extreme the use of 25–30 per cent. lead, with 1–2 per cent. of tin or nickel, gives a soft anti-friction metal which is lined into steel shells to give high-duty bearings for high-speed alternating-stress work, e.g. connecting-rod bearings in Diesel and aero-engines.

Resistance to Corrosion

Single-phase Alpha alloys are generally superior to those of duplex structure, but the individual alloying elements have an important effect, for it is these which determine the nature of surface film present on the material. In general the corrosion resistance of a metal or alloy is decided rather by the characteristics of its surface film than by the metal or alloy as such. Thus copper alloys containing aluminium develop a very resistant surface film of alumina. This is resistant to aerial corrosion and to certain forms of sea-water corrosion which are met with in marine condensers; it is self-healing, i.e. when broken by mechanical damage it will reform. Hence the excellent service of aluminium brass as marine condenser tubes. Ordinary brasses do not develop a resistant type of film, but one which readily breaks down by secondary reactions giving extensive attack. Additions of tin (Admiralty brass, 29 per cent. Zn, 1 per cent. Sn; Naval brass, 39 per cent. Zn, 1 per cent. Sn) are also employed to improve the corrosion resistance of brasses.

Nickel-copper alloys are also resistant to corrosion by sea-water, especially those of high nickel content. Tin bronzes, gunmetals, and silicon bronzes are resistant to aerial, sea-water, and acid corrosion, and are used extensively in pumps handling acid waters, in chemical plant, etc. Tin bronzes are also resistant to sulphite liquors, and are used extensively in the paper and cellulose industry.

Stress-corrosion Cracking

Severely cold-worked copper alloys, notably brasses containing 20–40 per cent. zinc, and silicon bronzes may suffer from intercrystalline cracking in normal storage or in service. This season cracking is caused by the combined action of residual stresses in the material and of some external mildly corrosive environment of the type which would not cause rapid general corrosion of the material, e.g. cracking in cold-worked brass is accelerated by atmospheres containing ammonia or by dilute solutions of ammonia or ammonium salts.

Tin bronzes, cupro-nickels, and aluminium bronzes rarely fail in service due

to corrosion cracking, but this can be induced by accelerated laboratory tests. Brasses can be rendered more resistant to season cracking by the addition of small amounts of silicon or antimony.

Season cracking in cold-worked copper alloys can generally be prevented by low-temperature heat-treatment, e.g. $\frac{1}{2}$ hour at 300° C. This treatment relieves internal stress, but is too mild to cause softening and re-crystallisation.

Fatigue and Corrosion Fatigue

When copper alloys are to be subjected to conditions of alternating stress, fatigue resistance becomes much more important than static strength. The failure of metals by fatigue is rapidly accelerated by corrosive conditions; e.g. some metals and alloys have lower fatigue resistances in air than in vacuum. Ferrous materials suffer severely from this effect, but copper alloys are much more resistant, e.g. under a salt spray 0·5 per cent. carbon steel gave only $\pm$ 2·8 tons per square inch, while phosphor bronze gave $\pm$ 14·6, and beryllium bronze $\pm$ 17·4. A corrosion-resisting nickel-chrome 18/8 steel under the same conditions gave only $\pm$ 15·8 tons per square inch. These figures indicate clearly that when corrosive conditions are combined with alternating stress or vibrations, e.g. as in marine engineering service, copper alloys are likely to prove most serviceable.

Welding and Brazing Characteristics

Like corrosion resistance and heat resistance, welding characteristics are governed by the chemical nature of the alloy constituents.

Copper alloys containing phosphorus and silicon are more readily weldable than other types, since these constituents form fluid slags with any oxides present or formed during the operation. Thus, phosphor bronzes and silicon bronzes weld more readily than other copper alloys, and the welding characteristics of brasses are markedly improved by the addition of silicon. Aluminium bronze is difficult to weld, due to its tenacious oxide film: special fluxes containing fluorides are used to overcome this difficulty, and arc welding gives better results than gas welding.

Brazing is generally applicable to copper alloys, the brazing alloys being copper containing phosphorus, silver, or zinc to lower the melting-point.

Soft-soldering is also readily applicable to copper alloys for joints which do not have to withstand stress at temperatures much above normal. Aluminium bronzes are again difficult to solder, due to the resistant oxide film, but the difficulty is again overcome by the use of special fluxes.

Impurities in Copper Alloys

Impurities in general have a rather less serious effect on the properties of alloys than on those of pure copper, but control of purity of materials is nevertheless essential, especially for alloys for hot or cold working, though less critical for castings.

In brasses, antimony is the most harmful common impurity, causing the brittle Delta phase to appear. On annealing, however, it is soluble to 0·06 per cent., hence has little effect on hot working. The limit for cold rolling is 0·03 per cent., or 0·01 per cent. when lead is present. Iron up to 0·1 per cent. has no effect on the working properties of brasses, and bismuth is less harmful than in pure copper.

In the tin-bronze group, aluminium is the most harmful impurity, since it destroys the good casting properties. Even 0·1 per cent. of bismuth is very harmful in hot-forging bronzes, e.g. coinage bronze. Its effects can be neutralised in copper, bronzes, etc., by a small addition of lithium.

In nickel-containing copper alloys, sulphur and carbon are the most harmful impurities. The Ni_3C which forms from carbon pick-up may graphitise on subsequent annealing. Thus carbon must be limited to 0·04 per cent. in nickel silvers.

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W. P. P.-W.

PLASTICS IN ENGINEERING

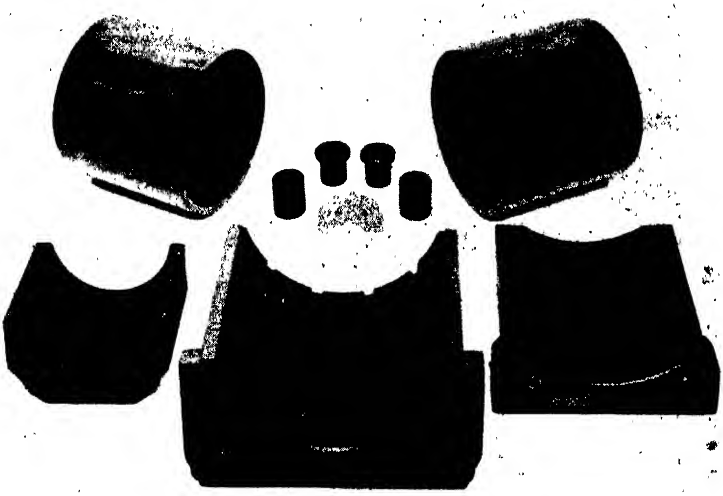

FIG. 1.—GROUP OF BEARINGS MACHINED FROM LAMINATED PLASTICS (*Bakelite, Ltd.*)

MOST engineering applications call for tough, impact-resisting materials, and it is for this reason that the engineer turns to laminated plastics, the only variety capable of fulfilling all his requirements. Certain moulded or cast materials are also used for such items as tool handles, machine cases, or even bosses for gear pinions, but it is the laminated materials which are mainly employed for the production of gears and heavy bearings.

Laminated plastics are resistant to most forms of corrosion, are unaffected by solvents, oil, petrol, grease, organic acids, and moisture, and will withstand high temperatures without changing dimensions. They are unusually resilient, being about forty times as resilient as steel, and will not adhere to metal; thus, gears and bearings made from them will never seize, nor will they score the metal parts, as all pieces of loose metal sink into the bearing. They afford easy response to sudden accelerating loads, all resultant shocks being absorbed in the plastic gear itself, which slowly and smoothly takes up the drive. Another important feature is that they can be lubricated with water, and used in the presence of oil and chemicals without adverse effect.

MECHANICAL ENGINEERING

Gears and Pinions

Many gears are now in use, and are made from laminated paper, or more often laminated fabric, bonded together with phenol-formaldehyde resin. They run equally well dry or immersed in oil or water, and can be mated with another plastic gear or, which is even better, with a steel pinion. When mated with another plastic gear, however, there is a possibility of them binding, due to the fact that they have corresponding friction coefficients.

The gears are generally machined from blanks of laminated material, although small gears, such as those used in instruments and clocks, are either punched out from the sheet or moulded from chopped fabric-filled phenolics. Another method is to mould the laminated fabric base material around a central boss which has previously been pressure moulded from some cellulose-filled

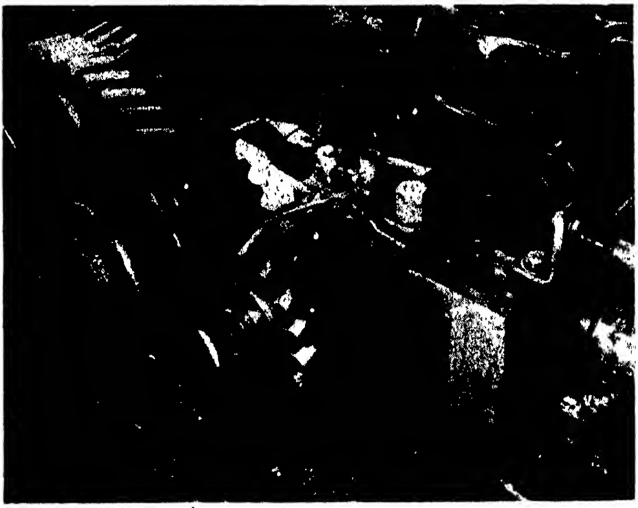

FIG. 2.—DOUBLE HELICAL GEAR MACHINED FROM LAMINATED PLASTICS
This gear transmits a 40-h.p. drive to a three-ram hydraulic pump in a Scottish shipyard.
(*Tufnol, Ltd.*)

phenolic plastic. Some gears have metal driving bushes moulded into them, metal wedges on the bush transmitting the drive to the plastic gear. A typical example of this type of gear is the timing gear used on automobile engines.

Other gears are reinforced with metal shrouds, thus increasing their load capacity. The strongest non-metallic gear in production, however, does not employ metal shrouds. This is the patented "Celoron Geolite" gear, which is built up of separate laminations of fabric base material bonded with metal

rivets, each lamination being disposed at an angle to the preceding one, thus achieving a spread of grain direction over each tooth of the gear. This avoids the zone of weakness prevalent in normally constructed gears, where the teeth at an angle of 45° to the longitudinal grain direction are, by a considerable amount, the weakest teeth in the gear.

An outstanding feature of all plastic gears and pinions is their quiet operation. Their application to various plants has done a great deal to reduce objectionable noises which arise from gear trains and rotating parts. Especially is this the case with clock mechanisms, automobile timing gears, variable-speed transmission machine drives, and reduction gears of all types.

Laminated pinions are to-day employed to drive industrial equipment of all types. They are successfully employed in sand mixers, in electroplating tumbling barrels, where they have withstood for years the attack of chemical

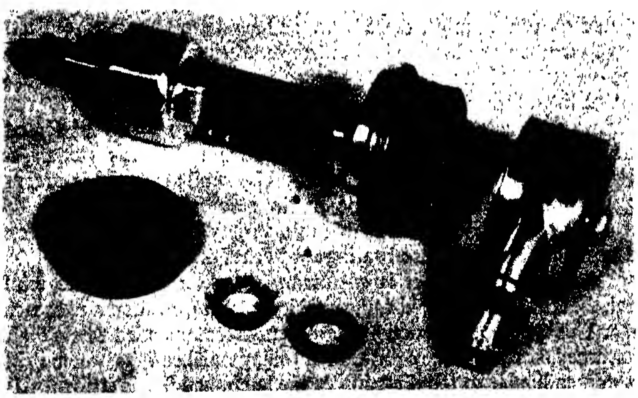

FIG. 3—AN AIR-TURBINE HAND-GRINDER WITH THE TOP REMOVED TO SHOW THE "TUFNOL" ROTOR, WITH THE ROTOR AND BALL-RACE CAGES SHOWN SEPARATELY

solutions, and as speed-reduction gears for lowering the operational speeds of small induction-type motors. One well-known food-mixing machine employs two laminated spiral gears for transmitting the drive from a single worm direct to two beater shafts. In this case the gears rotate in a specially designed grease-box, and have given satisfactory service over a wide range of loads and speeds.

Number Wheels and Pinions

Although polystyrene is finding many applications in the field of electrical and chemical engineering, its employment for the manufacture of wheels and pinions for special purposes is a more recent development. Prior to the introduction of polystyrene for the purpose, the number wheels and pinions used in direct-reading electricity, gas, and water meters were cast in high-grade tin alloy.

As an alternative material, polystyrene wheels and pinions have their advantages and disadvantages. Polystyrene may be moulded and finished with the highest degree of accuracy and finish demanded by these particular instruments. Because of the wide colour range possible with this material, good colour contrast and legibility may be obtained. In addition, polystyrene wheels and pinions are considerably cheaper than those made from tin alloy. They are not, however, suitable for use where temperatures exceed about 120° F.

Bearings

Bearings can also be made from laminated plastics of the fabric- or paper-base type, and are notable for their light weight, high mechanical strength, durability, and resistance to corrosion. They may be of almost any size, ranging from the large canvas reinforced phenolic bearing for use in rolling mills, to the small moulded phenolic composition pivot bearings for clock mechanisms. When used on rolling mills, these bearings have been known to outlast by as much as four times the life of similar bronze bearings. They run well in water, but the most satisfactory results are achieved when using a grease-water solution as the lubricant.

Bearings are made in several different ways. They may be fabricated from laminated tubes, blocks, or strips, or moulded from suitable materials, or may comprise a combination of these methods. The laminated tube is prepared by rolling the resin-impregnated fabric on to mandrels and pressing between heated semicircular moulds. Available in a variety of sizes, these tubes can be turned or milled with ease into bearings or bushes of any desired type.

For moulded bearings it is customary to use a scrap-fabric reinforced material, the fabric being mixed with suitable moulding powders and occasionally graphite. This type of construction is especially recommended where high loads are concerned, such as in the operation of rolling-mill bearings, where the load is always perpendicular to the direction of the laminated fabric strips.

Another type of bearing is that in which strips of plastic material are dovetailed into grooves cut into a suitable metal housing. Bearings of this nature are easy to assemble and do not require much maintenance.

Similar materials are also used in the production of ball-bearing retainers, and are highly successful for radial loads at high speeds. They have also proved satisfactory for the manufacture of cams for timing devices, for various types of couplings as employed in engine-driven generators, and for friction clutches of different kinds.

Stud-welding Gun

The unique properties of plastics as materials of construction are convincingly demonstrated in the case of the Nelson H-gun, an arc stud-welder, shown in Fig. 4. The requirements of a gun of this type are exceptionally onerous, both electrically and mechanically. Firstly, because the welding of the stud to the baseplate is brought about by the creation of a violent arc; secondly,

because of the severe jars caused by the operation of the control solenoid. In addition, the gun has to withstand the rough usage normal to any welding shop. After careful research, plastics material was found with the qualities desired, and the finished product is claimed to be superior to one made in aluminium alloy.

Synthetic Resin Core-binders

Considerable attention has recently been focused on the use of synthetic resins as binders for foundry sand-cores.

Of the thermo-setting or thermo-hardening resins most likely to meet the requirements of the foundryman, those of the phenol-formaldehyde and urea-formaldehyde types may prove most serviceable.

Technically, phenol resins, when cured by heat, as in the stoving of sand cores, are most resistant to hydrolysis and thermal decomposition than urea resins. They are probably adequate to meet the demands of the steel industry. They are less suitable for iron, brass-founding, and light-alloy castings, as they break down less readily at the lower pouring temperatures and so prevent easy knock-out.

Urea resins have given excellent performance in the latter industries, but have not yet been submitted to exhaustive evaluation with steel.

FIG. 4.—PLASTIC STUD-WELDING GUN

The body is moulded in a high-strength grade of phenolic material, and incorporates metal inserts, including the heavy copper solenoid shown. (*Bakelite, Ltd.*)

Urea-formaldehyde resins confer, by ordinary convection-oven stoving technique, the advantages of lower baking temperatures and shorter stoving times. Urea resin gives adequate dry tensile and compressive strength, has little or no adverse effect on permeability of the sand, and is low in gas evolution under thermal decomposition during pouring. To its detriment there are fumes to be contended with in foundry work, but these can be dealt with by forced-draught ventilation of stoving equipment.

Green Strength Modifiers.—Urea-formaldehyde resin may be obtained either as a viscous concentrated syrup or in a dry powder form, which, if necessary, can be redissolved in water. When fully cured by stoving, it becomes insoluble, giving a water-resistant bond. The resin is, however, almost completely devoid of the green-strength and plasticity requirements for sand-core moulding,

and it must therefore be used in conjunction with a green-strength agent. Cereals, starches, dextrines, clays, water-soluble gums, and soluble cellulose derivatives are all possible modifiers.

PLASTICS FOR TEXTILE MACHINERY

Plastics are finding ever-increasing use for the manufacture of textile machinery. When they were first introduced into the industry they were used for very small items which would have been relatively expensive to cast in the metal foundry, subsequently to be finished by grinding and polishing. Among these small parts were the condensers used on ring-spinning frames to control the ribbon of fibres. One of the smallest parts now made in plastics and formerly made of porcelain are the creel steps carrying the bobbins of slubbing, intermediate, and roving frames.

ELECTRICAL ENGINEERING

Because of the valuable insulating properties of plastic materials, the electrical industry quickly recognised their usefulness, and was probably the first to apply them on a large scale. With the development of new materials, many with the properties which are not found in combination elsewhere, the application of plastic materials within the electrical industry has steadily increased, and it is no exaggeration to say that without them the industry could not exist in its present form.

Heavy electrical engineering absorbs the highest proportion of the plastics consumed by the industry, though large quantities are used for cable-making and the coating of electric wires, for radio, tele-communication, and television, and for industrial and domestic electric fittings of all kinds.

The following survey deals with the most important of the plastic materials employed in the electrical industry.

Phenolics

Phenolic materials contribute more to the everyday need of the electrical industry than any other type of plastics. The electrical industry was one of the first users of phenolics, and its needs were in a large measure responsible for the rapid development of phenolic materials in their earlier years.

Moulding Materials.—Everyday electrical components moulded in phenolic materials, such as lamp-holders, meter boxes, switchplates, and the like, are produced from standard general-purpose materials, which provide good all-round mechanical and electrical properties in the finished moulding. It is important to realise, however, that these properties are capable of variation by the moulding material manufacturer. Many of the large number of grades of moulding materials now existing have been developed to meet requirements demanding emphasis on one or more particular property. Special low-loss materials, for example, find application in radio, in television, and in radar.

Again, anti-tracking materials have been developed for use where working

conditions are unusually severe and have been employed for mouldings used in automobile ignition systems.

Heat- and Chemical-resistant Materials.—Good heat resistance, necessary for many types of applications such as plugs for electric irons, kettles, coffee percolators, and bases of toast racks, can be achieved without sacrifice of good electrical properties.

The differential expansion of plastics and metal can cause serious trouble where large metal inserts are used in mouldings. If there is any fear that this may happen, crack-resistant plastic materials specially developed to overcome this defect should be used.

Resistance to chemicals is by no means a straightforward property, and different grades of phenolic moulding material exist, so that a decision on the correct material to adopt for battery tops, accumulator cases and other electrical gear in contact with chemicals is one demanding close collaboration with the moulding material manufacturer.

At the other extreme in the field of electrical insulation are moulding materials which have been specifically designed to be partial electrical conductors. These incorporate graphite to provide a useful leakage path, and a typical example of their use is for the production of moulded lightning arresters for the telephone industry.

Applications of Laminated Materials

The applications of phenolic laminated sheet, rod, and tube in the electrical industry are extremely widespread. In sheet form, the thinner grades find wide application in the telephone industry for the insulation of relay sets and telephone selector banks; thicker grades of $\frac{1}{8}$ in. upwards are adopted for relay coil cheeks, switchboard panels, and the like.

Bedplate Insulation.—Further applications include bedplate insulation on turbo-alternators and generators. This insulates the housing from the main body of the machine, and the weight upon it is often very considerable, calling for a material of high mechanical strength and which is not affected by the hot oil that may be thrown out by the machine. All holding-down bolts are also insulated with laminated bushes and washers, while laminated tubes are used to insulate cable leads and laminated sheet provides the terminal boards and instrument panels.

Strips cut from thick laminated sheet to form rigid bars some 1 in. square are adopted for high voltage (33,000-volt) fuse carriers. Similar strips are used for the contact operating links in 3,300-volt, oil-immersed contactors, and for the operating links on stator and rotor starters. Immersion in oil at high temperatures is frequently the lot of phenolic laminated, mercury-type on-load tap changing switches for power transformers being a typical example. Here, the switches are mounted on panels cut from sheet laminated material.

For heavy-duty industrial switchboards phenolic laminated material is adopted for supporting the busbars which carry 2,000 amps. on normal load and may carry 40,000 amps. under short-circuit conditions. The stresses set

up by this heavy current tend to force the busbars apart and demand great physical strength in the laminated supports. This strength factor often is as important as the electrical insulation qualities of the material.

Anti-tracking Laminates.—Urea plastics have a higher resistance to tracking than phenolic materials, and advantage has been taken of this fact in the development of special grades of laminates which have a surface of urea with a phenolic base. This urea facing has been successfully applied both to paper-base and fabric-base materials.

Post-forming Phenolic Laminates.—Materials that can be pressed to simple shapes in a similar manner to metal have been the subject of interesting electrical development, among which is the fuse-board shield now being used in prefabricated houses. The electrical properties of post-formed products are comparable with those of normal grades of fabric-base laminates, and other electrical applications include insulation for busbars, and channel fittings of all types.

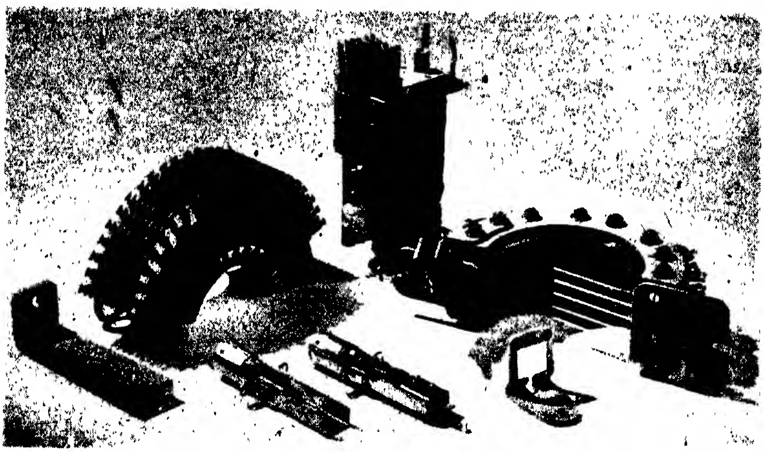

FIG. 5.—PLASTICS ARE EXTENSIVELY USED IN THE MANUFACTURE OF AUTOMATIC TELEPHONE PARTS

Although the parts are small, the large number in use makes this an important application. (*Bakelite, Ltd.*)

Resins, Varnishes, and Cements

Insulating varnishes were one of the earliest examples of the application of phenolic plastics to the electrical industry. The initial resin resulting from the reaction of phenol and formaldehyde is dissolved in suitable solvents and used as the impregnant for armatures, field coils, and electrical windings of all types. Cements are also produced, based on the resin, which are used extensively throughout the radio valve and electric lamp branches of the industry for fixing

the metal caps to the glass bulb. For this purpose the cement is used, naturally, entirely for its adhesive properties, and succeeds in uniting glass and metal with tenacity greatly exceeding the adhesion obtained with cements based on plasters of various types.

Amino Plastics

Translucent paper-filled urea mouldings in natural or very pale colours have good light transmission combined with high scattering power, and consequently find extensive use for lamp shades. These should be designed with sufficient ventilation to make sure that the temperature of the moulding does not go above 160° F., otherwise discoloration may occur. Shades are also fabricated from thin laminates, usually made from a single sheet of bleached sulphite paper of high *alpha*-cellulose content.

The very rapid curing of urea moulding powders in thin section enable lamp shades to be moulded very rapidly. The mouldings are light in weight and shatter proof. Their combination of good appearance and electrical resistance has led to their further use for ceiling roses, switchplates, power plugs and sockets, meter cases and similar applications where phenolics are more usually used for brown and black fittings.

Track Resistant and Stable Materials.—Some manufacturers, however, also use dark-coloured wood-filled ureas for power plugs and sockets, because of their track resistance. This is especially noticeable under conditions such as in the neighbourhood of an electroplating bath, where the surface may become damp and at the same time contaminated with an electrolyte, leading, in the case of phenolics, to a surface leakage current which may cause arcing and the formation of a carbon track, with complete breakdown of insulation. This does not happen with amino plastics, and for this reason ureas are used for fuse holders and bases.

Cellulose Acetate

Cellulose acetate plastics find a number of applications in the electrical industry in view of their many excellent physical properties, although their electrical characteristics are not of the same order as those of the hydrocarbon resin polymers, such as polystyrene, polythene, polyvinyl, carbazote. They are available as sheet, film, moulding powder, extruded sections, and lacquer solutions.

In spite of its poor chemical resistance and high water absorption, cellulose acetate has found a number of applications in the electrical industry, of which the following may be noted:

Film.—Wire and coil inter-layer insulation; slot insulation.

Mouldings.—Coil formers and choke housings; terminal blocks, grommets, switch dollies, and lighting fixtures; cradle arms (telephone hand-microphone sets); trafficator arms.

Sheet.—Instrument dials and escutcheons; radio dials; windows and scales; lampshades.

Polyvinyl Chloride

The biggest war-time outlet for P.V.C. was in the form of extrusion compound for cable insulation. It offers advantages over rubber, inasmuch as no vulcanisation process is necessary. P.V.C. is available in a wide range of bright colours, either opaque or transparent, and its low water absorption and resistance to corrosion and mechanical abrasion are added advantages.

Extrusion Compound.—Separate grades of extrusion compound are used for cable insulation and cable sheathing. In the former case, the component is extruded as a coating around the wire, which is drawn at comparatively high speed through a die across the orifice of the extrusion machine. In the latter case, the protective sheathing is similarly extruded around a cable consisting of one or more strands coated as above. P.V.C. extruded tubing is used in the aircraft industry for sleeving, conduits, and for the covering of flexible metal tubing.

Paste.—P.V.C. pastes have been used for the coating by dipping of branched cable ends. Also for insulation of the metal conducting suspensions used in electroplating.

Sheet.—An interesting application outside the cable field is for moisture-sealing washers fixed behind the dials of certain types of electrical instruments used in navigation.

Polystyrene

The high refractive index and high light transmission of polystyrene has popularised its use in certain types of optical systems. Its electrical properties are especially suited for barrier joints and terminal blocks for high-tension cables, and for the manufacture of coil formers, transformer bobbins, and high-frequency insulating components generally.

The present use of polystyrene in this country is largely directed to certain electrical applications in the radar and television fields.

Polythene

The commercial development of polythene coincided with the initial developments of radar, and the virtues of this new material were recognised as being of great importance to this electrical development. The advent of the war, which accelerated the development of radar, caused a definite orientation in the use of polythene, which, during the war years, was almost wholly supplied to the radar and allied industries. It made its maximum contribution as an insulator for cables operating at high frequencies, and many now well-known designs of cable were evolved round the use of polythene as the dielectric medium. These cables gave outstanding service over long periods of time. Subsidiary uses in radar apparatus took the form of injection and extrusion mouldings for cable terminations and other components.

Cable Applications.—The ease of handling polythene on conventional extrusion machinery, which was to be found in the majority of cable-makers'

works, led, as the years passed, to the increasing use of polythene in the manufacture of other types of communication cables, besides those operating at ultra-high frequencies. Since the end of the war, polythene continues to find a substantial use in the manufacture of cables and accessory equipment for use in television apparatus, but the major use at the present time is for the insulation of submarine telephone cables.

A logical development in the use of polythene followed from its employment in the manufacture of a variety of high-frequency communication cables, some of which operated up to 30,000 volts, namely, its employment in the power cable industry. Its advantages for power cables, operating at normal domestic voltages, derive from its good electrical insulation properties and from the ease of production of the cables. The electrical properties of polythene permit adequate insulation to be obtained with small radial thicknesses, thus decreasing the weight of the cable, which is further reduced by the fact that polythene has a very low specific gravity (0·92 grm./c.c.).

Polytetrafluoroethylene

Because of its special properties, this plastic can be used both in the electrical and radio industries, heavy engineering and chemical industries.

Initially it was found difficult to work and machine, but after considerable research these difficulties have been overcome, and production is now on a commercial basis, and the following applications to electrical engineering may be noted:

Valveholders, cathode-ray tube holders, wave guide components, co-axial cable connectors, sealed condensers and resistors, sealed volume controls, stand-off insulators, hermetic seals, sealing cans, wave-change switches, accumulator components.

The advancement of forming polytetrafluoroethylene into intricate shapes and sizes has overcome many of the difficulties that have faced the industry hitherto.

Silicones

Silicones are now produced commercially in various forms, such as fluids, insulating varnishes, and resins and elastics. They are particularly suitable, either used alone or in conjunction with inorganic materials, wherever the combined effects of heat and moisture are encountered.

Silicone insulation, with its greatly improved thermal resistance, means much longer life for electrical equipment, greater freedom from failure due to overloading and reduction of fire hazard, factors which may be particularly important in, for example, coal-mining machinery, where fire hazard must be reduced to a minimum and where periodic overloading frequently occurs. It also means that increased horse-power per unit weight can be obtained using silicone insulation, a fact of considerable importance in the aircraft industry.

FABRICATING THERMO-SETTING LAMINATES

No difficulty should be experienced in machining laminated materials. They can be turned, drilled, sheared, countersunk, tapped, shaped, milled, and shaved with ease. In general, the same operations and equipment which are employed in machining metal may be satisfactorily employed. Woodworking machines may also be used with these materials, but modifications are sometimes necessary in order to ensure satisfactory results.

Tools

Although special tools or equipment are not generally required, it is, however, advisable to reserve special tools for use on the material, as (*a*) advantage can be taken of the most suitable degrees of set for each operation, and (*b*) tools also used for working metal may, during the course of operation, transfer and embed particles of metal in the laminates, and thus impair their insulation properties. Tools should be kept free from swarf, particularly when sawing, drilling, and tapping blind holes, when a clogged tool may have an adverse effect on the quality of the work being produced. For this reason, especially when machining is to be undertaken in quantities, it is advisable to install an efficient plant for swarf and dust extraction.

In order to prevent fraying or chipping, where a cut runs off, blanks should be backed up with a rigid material, and the tool allowed to cut into this backing plate. Tungsten-carbide tools are normally used, although diamond tools are most suitable. Successful machining depends on the maintenance of a very keen edge. Cooling should be carried out by means of an air blast. For production work, however, time will be saved by using tools made from high-speed steel or alloys, such as Stellite, Type S.80, Wimet or Midia.

Lubrication

Generally speaking, laminated materials should be machined dry, but if a specially fine finish is required, this can be achieved by the use of small quantities of mineral oil. When tapping, it will often be found that the use of a little tallow is helpful, not only in facilitating the work, but in putting a fine finish on the thread.

On no account should suds, compound greases, soap or alkalis of any kind be applied to materials that are to be used for electrical purposes, because they impair the surface insulation. For the same reason, graphite, lead-pencil marks, or any trace of soldering flux should be removed.

Cementing

Pieces of laminated material can be cemented one to the other, as in the manufacture of built-up transformer bobbins, or for the holding of metal inserts in place.

There are many types of adhesive and sealing compounds specially made for bonding laminated materials, and for the making of water, oil, and petrol-resisting joints.

Drilling

This can be done on any standard drilling machine, but the use of high-speed drills, turning at the highest speed possible without burring, is recommended. For example, ¼-in. diameter drills should run at least at 2,000 r.p.m. for best results, while 10,000 r.p.m. is not excessive for a No. 60 drill. If small holes are required, it is better to use a high-speed driller.

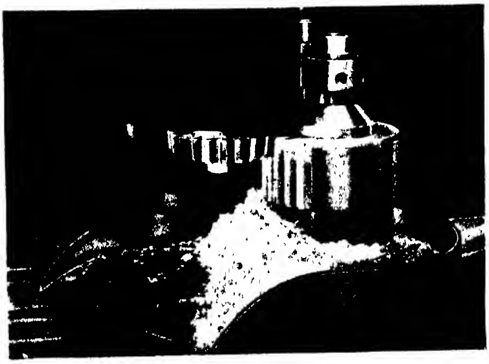

FIG. 6.—GEAR CUTTING
Cutting a "Tufnol" gear on a Fellows shaper.

When drilling at right angles to the laminations, the drills used should possess the following characteristics:

(*a*) The included angle of the point to be between 50° and 60°.

(*b*) A slow angle of "twist," or helix of the flutes.

(*c*) Flutes as wide as possible with long lead. Lips ground thin with little rake.

A rapid feed prevents the drill from lagging, but it should be withdrawn momentarily to cool, and to permit the removal of chips and swarf, at least once every ½ in. of feed.

For holes of 1 in. diameter and over it is recommended that the blank should be machined in a lathe by means of a boring bar and inserted tool.

In repetition drilling, care should be exercised when breaking through. If possible, the blank or piece should be reversed for the completion of the hole. Alternatively, the material should be backed up on the drilling table with a piece of hard wood.

The use of oversize drills, especially where close tolerances are needed, is necessary because of the tendency of the material to close in after the hole has been bored. Do not force the drill into the work, as if it is correctly sharpened only slight pressure is necessary.

Jigs should be made with a plate beneath the piece to be drilled to prevent breaking out, and it is advisable to try out the material before ordering jigs to ensure correct size of holes. In drilling deep holes, remove the drill frequently to clear the swarf. "Digging in" may be overcome by stoning the cutting edge

to give it a slight negative rake, and the drill should be fed rapidly but not forced.

When large holes are required in material up to $\frac{1}{4}$ in. thick, a wing cutter is frequently used. It should not rotate at a greater speed than about 160 r.p.m. for holes $1\frac{1}{2}$ in. in diameter, and even less for larger holes. A small pilot hole should first be made as a guide for the pilot of the wing cutter, and clean edges are assured if the hole is cut from each side of the material in turn.

The following table is given as an approximate guide for high-speed steel drills:

Diameter of Drill	*Approx. Revs. per Min.*
$\frac{1}{16}$–$\frac{3}{32}$ in.	12,000
$\frac{3}{32}$–$\frac{3}{16}$ in.	8,000
$\frac{3}{16}$–$\frac{5}{16}$ in.	4,000
$\frac{5}{16}$–$\frac{1}{2}$ in.	2,000
$\frac{1}{2}$–$\frac{5}{8}$ in.	1,300
$\frac{5}{8}$–$\frac{3}{4}$ in.	1,000
$\frac{3}{4}$–1 in.	700

FIG. 7.—MILLING
Milling "Tufnol" on a vertical milling machine.

Filing

Ordinary engineer's single- or double-cut files are quite satisfactory, but for very rough work, requiring considerable "breaking-down," Firth Brown cut milling files give good results.

Forming

Thin material of the proper grade can be formed in punch press operations (usually in heated dies) to produce cheaply cupped washers, right-angle pieces, etc. In addition, it can be creased or scored in properly designed dies to permit folding in assembly operations without fracturing the material. Punched shoulder bushings can also be produced in compound dies, providing the thickness of material is intermediate between the overall length and the shoulder thickness. This method reduces the cost of simple laminated bushings by about one-half, and enables manufacturers to replace bushings of rubber, porcelain, and moulded compositions with tough, strong parts.

When working thick material and for the most severe forming operations

with thin material, it should be softened by soaking in hot water and dried in forms mounted on hot presses, until it is dry enough to retain its shape. The ends of tubes can be formed inwards to a right angle, almost closing the tube, or outwards to form a shoulder.

Gear-cutting

Gear teeth may be cut on any milling machine or gear shaper with the usual milling cutters and tools. Speeds and feeds vary with the shape and size of teeth to be cut, but a peripheral speed of 140 ft. per minute is a good average speed when a high-speed milling cutter is being used. When the steel shrouds on shrouded gears are being cut, the speed should be reduced to 50 ft. per minute, and care should be taken, after the first shroud has been cut, to remove the steel swarf which would otherwise scratch the tooth face of the laminated material. Unshrouded blanks are usually cut dry, but an oil lubricant may be used when cutting steel-shrouded gears.

Grinding

Laminates can be satisfactorily ground on either sandpapering machines of the linisher type, on centreless grinders, or on vertical precision machines, while various jigs and arrangements can be devised for this purpose.

Grinding bands for the sandpapering machine should be open-grained garnet or flint, and the speed of the band should be between 1,500 and 2,000 ft. per minute. The centreless grinder should be run dry, and care taken to prevent clogging of the wheel, the surface of which should be periodically trued. Feeds may be up to 8 ft. per minute, with cuts up to 0·04 in. per run.

If it is desired to grind the material to fine limits in a vertical precision machine when assembling, the spindle ball-thrust races should be included above and below the main bearing. The normal wheel-cutting face of $\frac{3}{4}$ in. should be reduced to $\frac{1}{4}$ in. The recommended peripheral speed is 2,300 ft. per minute, and since the resinous base of the material has a tendency to glaze the wheel, a finer grit than 36 should not be used.

Knurling

Although these materials cannot be successfully knurled like metal because of their laminations, similar effects can, however, be obtained by (*a*) a thread of O.B.A. size chased on the component parts, on which a standard knurling tool is rotated one revolution afterwards, or (*b*) straight grooves cut at suitable intervals around the periphery of the component part.

Milling

Milling can be done on engineers' horizontal or vertical milling machines, or on woodworking horizontal or vertical spindle moulders. High-speed steel cutters with keen edges should be used with a relatively fine feed. Cutting speeds

vary with the tool, and should be run at a speed to suit the job. A cutter 5 in. diameter × 1 in. wide is satisfactory with a cutting speed of 400 ft. per minute.

Although higher speeds and feeds than for metals generally give the best results, single- or double-bladed fly cutters can also be used. Where the quantities required are large, and the amount of material to be used is small, it is often possible to feed pieces by hand through a high-speed wood-working shaper using cemented tungsten-carbide tool tips.

When using milling saws they should be hollow-ground and honed on the sides before use, to remove any burrs. The number of teeth is governed by the smoothness of the cut required. Saws with at least 6 teeth per inch are satisfactory and the teeth should be well backed off.

Planing and Shaping

When surface planing is necessary, as in the case of shaped cams, etc., the normal type of turning tool may be used with the rate of linear travel conveniently high, while the cut, generally, should be light.

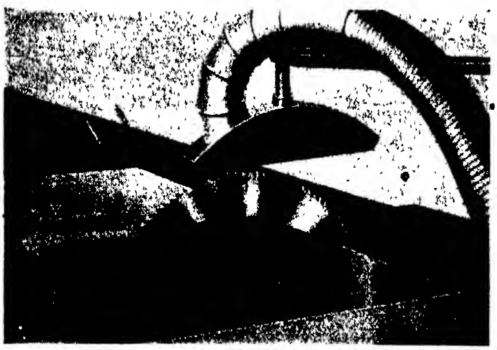

FIG. 8.—CUTTING SHEET
Circular saws may be used for cutting "Tufnol" sheets.

Polishing

Dry cotton or linen mops lightly applied to the material will produce a high polish. Application should not be heavy or the material will start to burn.

Punching

When punching laminates, the same general rules may be followed as when punching metal. Compression stripper plates are highly recommended and progressive dies will, in most cases, prove satisfactory, but generally speaking the normal piercing and blanking tools used for metal parts will give good results.

Although certain thicknesses can be punched cold, it is generally advisable to warm the material to a temperature of between 120° and 250° F., depending upon the grade being used. It is also an advantage to heat the die and punching tool. The ideal method of warming is by immersion in hot oil, the heat being thermostatically controlled.

Dies for punching should have a taper clearance of 1° to within $\frac{1}{32}$ in. of the top of the die. When working on material up to $\frac{1}{8}$ in. thick, there should be a clearance of 0·003–0·005 in. between punch and die.

It is important that due allowance be made for shrinkage when punching

laminates, especially when working to close tolerances, and in these circumstances punches should be made 0·002–0·003 in. *larger* for each $\frac{1}{32}$ in. thickness of material, and blanking dies 0·001–0·008 in. *smaller* than the size of the required blank. A good general rule to follow is : make punches to size + 0·005 in. and dies to size — 0·003 in.

Very smooth edges may be produced by using a shaving tool, which is similar to an ordinary punching tool except that the edges are bevelled, leaving a knife cutting edge.

When using strip material for punching, it may be found advisable to spring-load one side of the guide plate to take up any variation in the width of the strip. Such practice is also helpful in keeping the strip in position for follow-on work. Should lifting of the laminæ occur, it can generally be eliminated by making a fine negative taper on the punch.

Reaming

Reaming is most effective when accomplished at a speed approximating that used when reaming steel, and best results are obtained with the use of an expansion reamer in a floating holder which centres itself in the work. When the job warrants the expense, tungsten-carbide tip reamers are used.

Routing

The use of a power-operated router is recommended when irregular profiles are required to be cut, and particular care should be taken to keep the tools sharp. Especially good results are obtained on Wadkin Routers, types LSA or LUA, at speeds between 18,000 and 24,000 r.p.m.

Sanding

Any standard type of sanding machine using open-grained garnet or flint paper is suitable for preparing the surface of laminates for subsequent operations, e.g. to bind it to other materials such as plywood, or in de-burring after sawing.

Sawing

Laminated materials can be sawn with a joiner's fine-tooth hand-saw, but an engineer's hacksaw cuts more quickly and remains sharper longer. For production work, however, circular saws, band-saws, jig-saws, and fret-saws are used. In all cases the work should be fed as rapidly as possible without forcing.

Circular Saw.—This method is strongly recommended for cutting panels and strips where smooth edges and close tolerances are important. The saws should be used without set and, to avoid chipping of material, kept sharp, but where speed and not fine finish is the main consideration, a fine set will facilitate cutting and reduce the need for resharpening. Best results are obtained

FIG. 9.—TURNING

Normal metal-working technique may be adopted for turning "Bakelite Laminated," although feeds and the grinding of tools should be in accordance with recommended practice for best results.

when the saw is in such a position on the table that the highest point projects approximately $\frac{1}{2}$ in. above the surface of the material.

High-speed steel saws give longer life and better finish to the work, and when sharpening the saws always use a mechanical sharpener, as in hand sharpening the obtaining of correct concentricity with the bore is impossible. The teeth of the saw should all be of the same height, with sharp edges and no burrs, and they should not be radial, but have a positive lead, i.e. run slightly back from the centre line. The following specification is recommended for circular saws:

Material Thickness in.	*Speed r.p.m.*	*Circular Saw Specification*		
		Diameter in.	*Thickness in.*	*No. of Points per in.*
$\frac{1}{16}$	2,500–3,000	10	$\frac{1}{16}$	16
$\frac{1}{8}$	2,500–3,000	14	$\frac{3}{32}$	6
$\frac{1}{4}$ and up	2,500–3,000	14	$\frac{1}{8}$	6

Band-saw.—Where finish is not important and irregular profiles are required, or when a subsequent machining operation will be carried out, the use of band-saws will be found effective. The following is the recommended specification for band-saw practice:

Type of Part	*Speed r.p.m.*	*Band-saw Specification*		
		Width in.	*Thickness in.*	*No. of Points per in.*
Scroll . .	4,000–5,000	$\frac{1}{4}$–$\frac{3}{8}$	0·037	6 or 8
Discs up to 5 in.	4,000–5,000	$\frac{1}{4}$	0·037	6 or 8
Discs over 5 in.	4,000–5,000	$\frac{1}{2}$	0·037	6 or 8
Strips and blocks	4,000–5,000	$1\frac{1}{4}$–$1\frac{1}{2}$	0·042	6 or 8

Abrasive Saw.—The use of an abrasive saw, using high speed—15,000–16,000 peripheral feet per minute—combined with fast feed is a most effective method of cutting these materials, particularly when exceptionally smooth edges are required. The burr is considerably less prominent than that left by a metal saw and is quickly and easily removed.

Fret-saw.—A fret-saw can be used for cutting intricate shapes up to 1 in. thick, and the working speed should be between 500 and 600 strokes per minute. For cutting material up to ¼ in. thick, No. 10 fret-saw blades are recommended, but over this thickness and up to 1 in. thick, blades having 9 teeth per inch should be used. Sawn edges can be made smooth by filing or scraping.

Screw-cutting

Standard methods are satisfactory in cutting Whitworth and other threads, and the compound rest need not be altered. The screw-cutting tool should be ground to cut one side only and advanced for each cut as with mild steel. Tungsten-carbide tools ground with no top rake and 8–10° clearance on the end and side prove most satisfactory: Speeds and feeds should be equivalent to those used when screw-cutting mild steel, and the use of a light oil will assist in obtaining a clean thread. Threads should be finished off with a chaser having the same rake and clearance as those used on turning tools, but without the hook used in cutting steel.

Shearing

Laminated materials can be sheared quickly and accurately on either hand- or power-operated guillotines, using the latter for the thicker sheets. The clearance between the blades of the machine should not exceed 0·003 in., while the clearance on the cutting edge of the blade should have a 5° clearance angle.

In the grades specially made for cold punching, these materials can be sheared cold up to $\frac{1}{16}$ in. in thickness. Should, however, a slight surface cracking at the edge be experienced, the material should be warmed to a temperature of about 120° F., but it should not be allowed to remain on the hotplate or in the oven for more than 3–5 minutes.

Spindle Moulding

The spindle moulding of laminated plastics is undertaken on standard wood-working spindle machines, but effective work can be turned out on all types, even on the small machine used in the home workshop. As in most other machining operations, high speeds combined with fast feed give the best results. In fact, use the highest possible speed without burning.

The use of tungsten-carbide tip tools is highly recommended, since in many cases this type of tool will give as much as thirty times the amount of work before regrinding is needed compared with the normal tool made from high-speed steel.

Spindle-moulding machines can also be effectively used for purposes other than the shaping of strips to a required pattern. They can be used to trim strips of the material to size within fine limits, at the same time giving a perfectly clean edge. Boxes and cases made from laminated materials can be trimmed, a fine finish given to the edges and, if desired, a radiused edge as well, with the use of these machines.

Tapping

When tapping laminated material, the taps must be kept sharp. A three-flute tap is sometimes an advantage, but this additional clearance will not compensate for a blunt cutting edge. The material should be clamped to a vice when tapping parallel to the laminations.

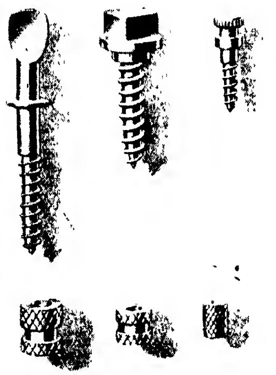

FIG. 10 (*top*).—TYPES OF SCREWS FOR MOULDING-IN; (*bottom*) TAPPED INSERTS FOR MOULDING-IN

High-speed taps 0·002–0·005 in. oversize are recommended. A slight chamfer around the edge of the hole before tapping prevents lifting of the laminæ, and a little tallow rubbed on the tap before use will facilitate this operation and ensure a clean finish. Suitable speeds for drilling and tapping holes in rod, from 4 B.A. up to ½ in. Whitworth, with an ordinary capstan lathe and No. 2 type tapered taps are as follows:

	r.p.m.
Drilling	900
Tapping . . .	200
Clearing tap	750

Trepanning and Counterboring

Trepanning is undertaken on drilling machines using standard wing cutters, the running speed being dependent upon the size of the piece, i.e. small diameters fast and large slow. The board to be trepanned should be marked out for the required diameter, and the centre drilled, the size of hole corresponding with the pilot of the trepanning tool. The blanks should not be cut completely from the sheet at one setting. It is preferable to trepan nearly through, and then reverse the board to complete the operation and thus ensure a clean cut with no fraying.

Recessing or counterboring can be carried out by using a counterbore of standard design. The pilot hole used during the trepanning operation again functions as a location for the counterbore centre.

Turning

In turning, the same rules apply as in wood turning, but always use the highest possible speed, or the greatest surface feed per minute. The tools should be kept sharp and the rakes and cutting angles should follow woodworking

practice, but with slightly less clearance on the cutting edge. Cemented tungsten-carbide tool tips are specially recommended where practicable.

Tool bits should be ground without a top rake to a cutting angle of approximately 80°, with a clearance of 10–12°, and set with the point on the centre of rotation of the work. The cut can be from $\frac{1}{64}$ in. to $\frac{1}{8}$ in., but the feed should be 0·030 in. regardless of the cut.

Cutting speeds may vary according to the grade of sheet and type of job, from 100 ft. per minute to 500 ft. per minute for all depths of cut, but if excessive resharpening is found necessary, the speed may be reduced until an economical speed is determined.

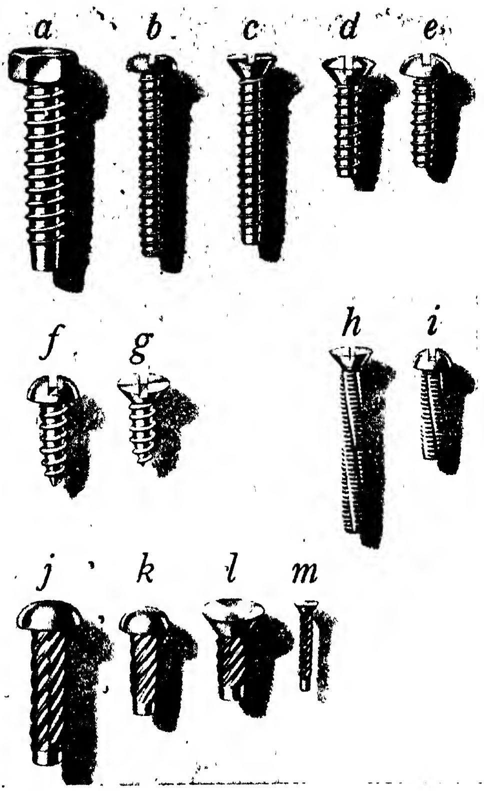

FIG. 11.—VARIOUS TYPES OF SELF-TAPPING SCREWS

The types shown are: (*a*) Hex head "Z" type; (*b*) binding head "Z" type; (*c*) countersunk head "Z" type; (*d*) raised head "Z" type; (*e*) round head "Z" type; (*f*) round head "A" type; (*g*) countersunk head "A" type; (*h*) countersunk head "Beco"; (*i*) round head "Beco"; (*j*) and (*k*) round head "U" type; (*l*) and (*m*) countersunk "U" type.

METHODS OF JOINING PLASTICS

Plastic products, like similar parts in other industries, need fastening together in some manner in order to form the complete article and, in many cases, the final assembly calls for the attachment of metal fittings such as are used in cameras, torches, wireless sets, etc.

Various methods of fastening are adopted, and, except where the employment of inserts is called for, are made with the same screws and screwed appliances as are used in the metal trades.

Selection of the most suitable fastener is important, and careful considera-

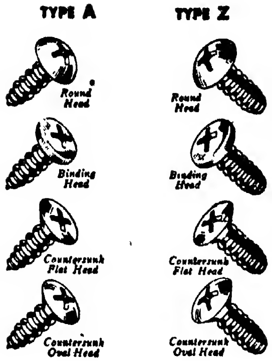

FIG. 12.—SELF-TAPPING SCREWS WITH PHILLIPS RECESS HEAD

tion must be given to the following points before deciding on the type of fastener to be used:

(1) What strength is required in the assembly.

(2) What will be the appearance of the fastener.

(3) Which is the best and most convenient method necessary for the production of large quantities of one assembly.

(4) Is the assembly to be a permanent one.

(5) If not, how often are the parts to be separated.

(6) Will there be a continuous stress on the threads.

(7) What tolerance is necessary for the thread form.

Each of these factors plays its part in governing the final selection of the best all-round type of fastener suitable for the job.

Methods of Preparation

Preparation for its use necessitates the adoption of one of the following methods, all of which are in general use:

(1) The moulding-in of a threaded hole for reception of the screw fastener.

(2) The moulding-in, or pressing-in after moulding, of a metal insert.

(3) The moulding-in, or drilling after moulding, of a plain hole which is subsequently tapped.

(4) The moulding-in, or drilling after moulding, of a plain hole for reception of a self-tapping or drive screw.

With method (1) it must be remembered that a moulded-in thread does not possess the same strength as its metal counterpart, and is therefore only suitable where the loading is low. Method (2) is mainly used where an assembly is to be frequently dismantled, but in this case great care must be given to the selected design of insert, in order to ensure that it does not turn or pull out after moulding. Owing to the great expense involved, the use of inserts is now being greatly superseded by method (4), which specifies the employment of self-tapping screws.

In method (3) a plain hole is either moulded-in or drilled after moulding, and then subsequently tapped, but this procedure is slow compared to method (4), which is perhaps the most modern practice of all. Here a plain hole is either moulded-in or drilled after moulding as in method (3), but instead of tapping the hole a self-tapping screw is used, thus eliminating the time, cost, and risk involved by other methods.

Inserts

FIG. 13—AEROTIGHT NUTS

These are generally made of brass, and although usually moulded direct into the plastic, can be forced into the hot piece after removal from the mould, subsequent cooling shrinking the piece around the insert, thus holding it securely in position.

Inserts are mostly used where the continuous removal of assembled parts is called for, but their employment, until quite recently, resulted in one great drawback, namely, that if damaged they could not easily be removed without causing injury to the part concerned. This has, however, been overcome with the introduction of a replaceable insert which, on removal, leaves a threaded hole that can then be used for the fitting of another insert.

Self-tapping Screws

The time and cost involved in the use of inserts, whether replaceable or not, is so great that whenever possible the employment of a self-tapping screw is to be preferred.

This screw is widely used in the metal trades, and consists of a hardened screw, of varying thread form according to the use to which it is to be put. When screwed into a drilled or moulded-in hole (slightly undersize), it cuts the material into its own form, thus creating a threaded hole from which it can be unscrewed and rescrewed several times without damaging the thread. It can be either hand or power driven by screwdriver or spanner, according to the type selected.

Types "A" and "Z," as illustrated in Fig. 11 (*a–g*), are recommended for fastenings which are to be frequently dismantled or where rivets cannot be satisfactorily employed owing to inaccessibility. They are produced in a variety of head shapes and sizes, a special hexagon-headed type being made for heavy assemblies or where the use of a ratchet spanner assists in rapid production.

"*Beco*" *Type*.—The "Beco" type self-tapping screw (Fig. 11 (*h* and *i*)) has been specially designed for use where fastenings are to be made in phenolic or urea base compounds.

It is similar to the type "Z," but is fluted down the shank in order to give it a "tapping" effect when screwed into the material. The subsequent threads are of standard pitch; thus, in the event of a screw being lost from an assembly, it can easily be replaced by an ordinary machine screw of the same pitch.

Phillips Head.—If the type of screw selected entails the use of a screwdriver, then one with a Phillips recessed head is to be recommended. The heads are suitably recessed to fit a specially shaped screwdriver, the main advantage in favour of their use when assembling plastic parts being that the screwdriver cannot slip out and scratch the material (see Fig. 12).

The driver also keeps the screw on the axis of the hole, thus ensuring a

perfect fit, and should any awkward angle in the assembly be encountered, the screw remains on the screwdriver until driven home.

Drive Screws

The drive screw, like the self-tapping screw, cuts its own thread on entering the material, and is considered to be the cheapest and easiest method for use in assemblies calling for permanent fixtures (see Fig. 11 (*j–m*)).

Designated type "U," it can be hammered or forced into a slightly undersize hole in the parts concerned, the unthreaded portion of the screw serving to hold it in position and pilot it down the prepared hole.

Drive screws prove difficult, if not impossible, to remove, and are therefore most suitable for applications in which the fastening is to be permanent.

Riveting

Riveting provides another method of fastening where plastics of an impact-resisting nature are concerned, but great care must be taken to correctly position the riveting hammer so that the rivet head is not excessively upset.

Threaded bushes with riveting portions are successfully employed in sheet plastics, but here again great care is needed to avoid excessively upsetting the riveted flange. Bosses can also be moulded on the product and then riveted over the mating part by the application of heat, but, except in the case of the independently threaded boss, riveting is only applied where permanent fastenings are called for.

Self-locking Nuts

Self-locking nuts, such as the "Aerotight" shown in Fig. 13, can be used for all assemblies, where the use of a bolt is preferred to that of a self-tapping or drive screw, and where assemblies are subject to excessive vibration. Made in a variety of sizes, weights, and materials, the nut is not affected by oil or water, and can be used at moderately elevated temperatures.